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FLUIDS FOR SUBMARINE EXTERNAL HYDRAULIC SYSTEMS

RESEARCH AND DEVELOPMENT REPORT 95 680J
SUB-PROJECT S-R001 07 01
TASK 0619

20 JANUARY 1964

BY

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Annapolis, Maryland

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U. S. NAVY MARINE ENGINEERING LABORATORY

ANNAPOLIS, MARYLAND

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ABSTRACT

A SUCCESSFUL SEARCH WAS MADE FOR PETROLEUM-BASE HYDRAULIC FLUIDS WITH RUST-INHIBITING QUALITIES ADEQUATE TO PREVENT RUSTING IN SUBMARINE HYDRAULIC SYSTEMS CONTAMINATED WITH SEAWATER. RUSTING OF SUCH SYSTEMS HAS BEEN A SERIOUS SERVICE PROBLEM. FLUIDS OF TWO TYPES WERE FOUND WITH CONSIDERABLY GREATER RUST-INHIBITING ABILITY THAN CURRENTLY USED NAVY HYDRAULIC FLUIDS. THE TYPE OF FLUID GIVING THE BETTER RUST INHIBITION DEVIATED FROM PRESENT HYDRAULIC FLUID SPECIFICATION REQUIREMENTS IN THAT IT EMULSIFIED READILY WITH CONTAMINATING SEAWATER, WHEREAS THE SECOND TYPE DID NOT. OTHER NECESSARY PROPERTIES OF BOTH FLUID TYPES WERE SATISFACTORY.

FEASIBILITY OF USING THE EMULSIFYING-TYPE FLUID IN SUBMARINE HYDRAULIC SYSTEMS WAS SHOWN BY 1000 HR OF SATISFACTORY OPERATION USING A HYDRAULIC SYSTEM MOCK-UP WITH FULL SCALE SUBMARINE SYSTEM COMPONENTS IN THE PRESENCE OF 10% SEA-WATER CONTAMINATION. TECHNICAL SPECIFICATION REQUIREMENTS FOR THIS TYPE FLUID WERE DRAWN UP.

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FLUIDS FOR SUBMARINE EXTERNAL HYDRAULIC SYSTEMS

1.0 INTRODUCTION AND BACKGROUND

DURING THE PAST SEVERAL YEARS, THE CHRONIC PROBLEM OF SEA-WATER ENTRY INTO THE EXTERNAL HYDRAULIC SYSTEMS OF SUBMARINES HAS BECOME ACUTE. THE EXTENDED USE AND OLD AGE OF CONVENTIONAL DIESEL-ELECTRIC-DRIVE SHIPS HAS CREATED PROBLEMS OF EVER INCREASING MAGNITUDE IN SEALING OUT SEAWATER. IN THE NEWER NUCLEAR-POWERED SUBMARINES, THE PROBLEM OF SEA-WATER ENTRY IS ACCENTUATED BY CHANGES IN BOTH DESIGN AND TACTICAL USE OF THE SHIPS. DESIGN CHANGES ARE CHARACTERIZED MAINLY BY USE OF ACTUATING DEVICES OUTSIDE THE SHIP'S PRESSURE HULL, USE OF SEPARATE EXTERNAL AND INTERNAL (MAIN AND VITAL) HYDRAULIC SYSTEMS, AND INCREASES IN OPERATING PRESSURES. TACTICAL USE OF SUBMARINES HAS BEEN EXPANDED TO OPERATION AT HIGHER SPEEDS AND GREATER DEPTHS. BOTH FACTORS PLACE AN EVEN GREATER STRAIN ON SYSTEM SEALS AND WELDED JOINTS THROUGH THE PRESSURE HULL. THESE CHANGES HAVE REQUIRED BETTER STATIC AND DYNAMIC SEALS IN THE SYSTEMS EXTERNAL TO THE HULL TO PREVENT LEAKAGE OF SEAWATER INTO THE SYSTEMS. THE FLUID USED IN MOST DIESEL-ELECTRIC-DRIVE-TYPE SUBMARINE SYSTEMS AND IN THE EXTERNAL SYSTEM OF THE NUCLEAR-POWERED SHIPS IS MILITARY SYMBOL (MS) 2110-H (VISCOSITY OF 90-120 SAYBOLT SECONDS UNIVERSAL (SSU) AT 130 F), COVERED BY MILITARY SPECIFICATION MIL-L-15017A.[1] IT SHOULD BE NOTED THAT CERTAIN EQUIPMENT EXTERNAL TO THE PRESSURE HULL IS OPERATED FROM THE VITAL HYDRAULIC SYSTEM, USING A MORE VISCOUS PETROLEUM FLUID. WHILE THE POSSIBILITY OF CONTAMINATION OF THE INTERNAL HYDRAULIC SYSTEM VIA THIS EQUIPMENT EXISTS, THE INCIDENCE OF FLEET CASUALTY REPORTS INDICATED THAT THE NEED FOR IMPROVEMENT WAS GREATEST IN EXTERNAL SYSTEMS. THEREFORE, THE SCOPE OF THIS WORK WAS AIMED AT IMPROVEMENT OF THE EXTERNAL SYSTEM FLUID.

1.1 <u>PREVIOUS WORK</u>. THE MAGNITUDE OF THIS PROBLEM HAS BEEN SUMMARIZED IN AN EARLIER REPORT UNDER THIS TASK (REFERENCE (A)). UNCLASSIFIED REPORTS FROM FLEET OPERATION, SUCH AS REFERENCES (B) AND (C), DESCRIBE CURTAILMENT OF SHIP OPERATION AND EXPENDITURE OF MANY THOUSANDS OF DOLLARS FOR A SINGLE CASUALTY DUE TO SEA-WATER ENTRY IN HYDRAULIC SYSTEMS. REALIZING THE SERIOUSNESS OF THE PROBLEM, THE BUREAU OF SHIPS AUTHORIZED A TWO-PRONGED APPROACH TO ITS SOLUTION. FIRST, BECAUSE A TWO-PHASE AQUEOUS-PETROLEUM OIL HYDRAULIC FLUID EXISTED IN THE SYSTEM AFTER SEA-WATER ENTRY HAD BEEN ENCOUNTERED, REFERENCES (D) AND (E) INSTRUCTED AFFLICTED SHIPS TO ADD CONCENTRATED AQUEOUS SODIUM CHROMATE (A STANDARD CORROSION INHIBITOR FOR DIESEL ENGINE

[1] ABBREVIATIONS USED IN THIS TEXT ARE FROM THE GPO STYLE MANUAL, 1959, UNLESS OTHERWISE NOTED.

AQUEOUS COOLING SYSTEMS) TO MINIMIZE CORROSION UNTIL THE SYSTEM COULD BE FLUSHED TO REMOVE SEA-WATER CONTAMINATION. SECOND, IN REFERENCE (F), THE BUREAU AUTHORIZED THIS LABORATORY TO PROCEED ON A LONG-RANGE PROGRAM AFTER COMPLETING THE EVALUATION OF CHROMATE AUTHORIZED EARLIER IN REFERENCE (G).

1.2 FINDINGS. EVALUATION OF THE USE OF CHROMATE WAS REPORTED IN REFERENCE (H). IN SUMMARY, CHROMATE IS OF DOUBTFUL VALUE BECAUSE OF THE HIGH (1:1) VOLUME RATIO WITH SEAWATER REQUIRED FOR PROTECTION AND BECAUSE OF EXCESSIVE SLUDGE FORMATION AND PRESSURE DROP IN FILTERS OF A CIRCULATING SYSTEM. REFERENCE (H) ALSO DESCRIBED INITIAL WORK ON THE LONG-RANGE ASPECTS OF THIS PROBLEM, NAMELY, DEVELOPMENT OF AN IMPROVED HYDRAULIC FLUID. INITIAL RESEARCH WORK FOR IMPROVEMENT OF RUST INHIBITION OF MIL-H-15017A FLUID BY INOCULATION WITH MORE POTENT INHIBITORS WAS ABANDONED WHEN PROMISING FINISHED EXPERIMENTAL FLUIDS WERE OFFERED BY SEVERAL COMMERCIAL OIL SUPPLIERS. THIS REPORT DESCRIBES EVALUATION OF ALL SUCH FLUIDS STUDIED IN THIS PROGRAM.

2.0 APPROACH

EARLY CORRESPONDENCE WITH SUPPLIERS OF INHIBITORS AND FINISHED FLUIDS INDICATED TWO AVENUES OF APPROACH TO A SOLUTION OF THE PROBLEM. THE MORE CONSERVATIVE WAS FURTHER RUST INHIBITION OF MIL-L-15017A TYPE FLUID, MAINTAINING ALL OTHER PROPERTIES UNCHANGED AS MUCH AS POSSIBLE. THE SECOND APPROACH CONSISTED OF OBTAINING MAXIMUM RUST PREVENTION IN A PETROLEUM-BASE FLUID, REGARDLESS OF ITS EFFECT ON THE OTHER OIL PROPERTIES. IT WAS SOON EVIDENT THAT THE MAIN DIFFERENCE IN THESE APPROACHES CENTERED AROUND EMULSIBILITY. RUST-INHIBITING PROPERTIES OF MIL-L-15017A FLUID COULD BE IMPROVED APPRECIABLY WHILE MAINTAINING SPECIFICATION DEMULSIBILITY. FLUIDS A AND C ARE EXAMPLES. STILL FURTHER IMPROVEMENT WAS POSSIBLE IF MORE POWERFUL INHIBITORS, WHICH ARE ALSO INHERENTLY GOOD EMULSIFIERS, WERE USED. FLUIDS B AND D ARE EXAMPLES OF THIS APPROACH. THE LEVEL OF RUST PROTECTION REQUIRED IN SERVICE AND THE ALLOWABLE EXTENT OF DEVIATION FROM THE LONG ESTABLISHED USE OF NONEMULSIFIABLE FLUID WERE UNKNOWN AT THE START OF THE PROGRAM. IT WAS OBSERVED, HOWEVER, THAT ALL SAMPLES TAKEN FROM OPERATING SUBMARINES IN SERVICE WERE READILY EMULSIFIABLE, PROBABLY DUE TO TRACES OF SOLIDS AND POLAR OIL OXIDATION PRODUCTS. FOR EXAMPLE, A SAMPLE TAKEN IN SEPTEMBER 1961 FROM THE EXTERNAL SYSTEM OF USS SKATE (SS(N) 578) CONTAINED 16% SEAWATER THAT FORMED AN EMULSION WHICH WAS STABLE FOR SEVERAL WEEKS.

3.0 METHODS OF FLUID EVALUATION

THE FLUID EVALUATION PROGRAM CONSISTED OF FIVE MAIN DIVISIONS OF EFFORT. THE FIRST OF THESE WAS CONDUCT OF LABORATORY SCREENING TESTS FOR RUST PREVENTION. FLUIDS WHICH DID NOT MEET TARGET REQUIREMENTS HERE WERE DROPPED FROM THE PROGRAM. NEXT, THE PROPERTIES SPECIFIED BY THE PRESENT SPECIFICATION FOR FLUIDS FOR THIS APPLICATION,

MIL-L-15017A, were determined to obtain a measure of the deviation of candidate fluids from those presently approved. These results were used later to formulate the proposed specifications for fluids for submarine hydraulic systems. Following this, several non-specification tests were performed to evaluate fluid properties in areas of special concern. After a review of the data thus collected, candidate fluids were tested in two hydraulic pumps. The first of these was a preliminary evaluation in a small pump, the purpose of which was to eliminate fluids of doubtful utility from final evaluation in an expensive full scale service-type pump. The last step in fluid evaluation was operation in a full scale pump similar to that used in submarine hydraulic systems.

4.0 LABORATORY SCREENING TESTS

4.1 Screening Tests for Rust Prevention. The most important property required of a satisfactory fluid is its ability to inhibit system rusting in the presence of gross sea-water contamination. Fleet submarine casualty reports from late 1960 to early 1962 were reviewed to obtain some estimate of the extent of contamination. The percentages chosen for this study represented broadly the conditions reported there. Several procedures were used in an attempt to produce the most likely of several extreme rusting conditions. The tests were described in detail in reference (h). The two most useful procedures are summarized below.

4.1.1 Modified Static Water Drop Test. The static water drop test of reference (i) was used to simulate mild static rusting conditions. In this test, a drop of water is placed on a mild steel specimen immersed in approximately 25 ml of the fluid under investigation. The test was modified by the use of a drop of seawater instead of the specified fresh water. Daily observations were made for 15 days.

4.1.2 Modified ASTM D665 Test. This test was used to simulate intermittent shipboard hydraulic system operation. The method given in reference (j) was modified as follows:

- Use of equal volumes (150 ml each) of fluid and seawater.
- Stirrer operated 1/4 hr per day.

4.1.3 Performance Level Desired. Target requirements in these tests for a fluid to be considered eligible for pump testing are summarized below with typical results for a MIL-L-15017A fluid shown for comparison.

Method	Target Requirement	MIL-L-15017A Fluid Result
Static water drop test	No rust after 15 days	Severe rust in 1 day
Modified D665 test	No rust after 30 days	Severe rust in 1 day

4.1.4 Results of Tests for Rust Prevention. A total of seven fluids were evaluated in the course of this program. Laboratory screening-test results on the first two fluids were reported in reference (h). These results are repeated for convenience in Table 1 together with similar data on the other fluids.

Table 1
Laboratory Screening Rust Test Results

Test Method	Fluid						
	A	B	C	D	E	F	G
Static water drop test							
Days exposed:	6	12	35	24	1	1	1
Observation at end of test:	1/4 of drop area rusted	<1/10 of drop area rusted	No rust	No rust	Severe rust	Severe rust	Severe rust
Modified D665 test							
Days exposed:	30	30	35	63	1	1	1
Observation at end of test:	No rust	No rust	No rust	No rust	Severe rust	Severe rust	Severe rust

These results show that only the first four fluids approached the target requirements. Further tests on Fluids E, F, and G were accordingly discontinued. Fluid A gave borderline-to-poor results in the static water drop test. When advised of this fact, the supplier provided Fluid C, of similar composition but with a larger inhibitor dosage. Further work was therefore performed only on Fluids B, C, and D.

4.2 SCREENING TESTS FOR MIL-L-15017A REQUIREMENTS. FOLLOWING SUCCESSFUL RESULTS IN THE RUST-PREVENTION SCREENING TESTS, PHYSICAL AND CHEMICAL PROPERTIES OF SPECIFICATION MIL-L-15017A NEXT WERE OBTAINED. THESE TESTS WERE MADE (A) TO ESTABLISH THE FLUID AS AN EMULSIFIABLE OR NONEMULSIFIABLE TYPE AND (B) TO DETERMINE THE EXTENT OF DEVIATION OF THE CANDIDATE FLUID FROM MIL-L-15017A REQUIREMENTS PRESENTLY USED TO EVALUATE HYDRAULIC FLUIDS FOR SUBMARINE HYDRAULIC SYSTEMS. THE RESULTS OF THESE TESTS ON FLUIDS B, C, AND D, GIVEN IN APPENDIX A, SHOW THAT THESE FLUIDS MET THE REQUIREMENTS OF MIL-L-15017A FOR VISCOSITY, POUR POINT, FLASH POINT, COPPER STRIP CORROSION, CARBON RESIDUE, FOAMING CHARACTER, PRECIPITATION NUMBER, AND, OF COURSE, RUST PREVENTION WITH SEAWATER. THE WORK FACTOR TEST, WHICH MEASURES OXIDATION STABILITY, WAS NOT PERFORMED. ALL FLUIDS, HOWEVER, DEVIATED FROM SEVERAL OF THE REMAINING REQUIREMENTS OF THAT SPECIFICATION. THESE DEVIATIONS ARE SUMMARIZED IN TABLE 2.

TABLE 2
DEVIATION OF CANDIDATE FLUID PROPERTIES
FROM MIL-L-15017A REQUIREMENTS

PROPERTY	MIL-L-15017A REQUIREMENT	FLUID CODE B	C	D
NEUTRALITY	NEUTRAL	-	-	ALKALINE
ACID NO.	0.2 MAXIMUM	0.08	1.12	-
BASE NO.	0.2 MAXIMUM	-	-	0.53
SAPONIFICATION NO.	0.5 MAXIMUM	2.2	2.3	2.0
WATER, %	NONE	0.1	-	0.3
EMULSION (DISTILLED WATER)	DEMULSIBLE IN 30 MIN	REMAINS EMULSIFIED *	-	REMAINS EMULSIFIED *
SULFUR, %	0.50 MAXIMUM	0.54	-	-

*THE FLUID WAS PURPOSELY FORMULATED TO REMAIN EMULSIFIED WITH FRESH- AND SEAWATER.

THE DEVIATIONS OF THESE FLUIDS FROM MIL-L-15017A REQUIREMENTS, OTHER THAN THE INTENDED EMULSIBILITY OF FLUIDS B AND D, ARE HIGH ACID, BASE, AND SAPONIFICATION NUMBERS. IN ADDITION, FLUID A WAS SLIGHTLY

HIGH IN SULFUR CONTENT, FLUID D HAD AN ALKALINE REACTION, AND BOTH FLUIDS CONTAINED A FEW TENTHS PERCENT OF WATER. THE EFFECTS OF THESE DEVIATIONS, AS SUCH, ARE NOT EXPECTED TO BE SIGNIFICANT, AND, IN THE ABSENCE OF POSITIVE EVIDENCE OF UNSATISFACTORY FLUID PERFORMANCE, SHOULD BE MERELY DESCRIPTIVE OF FLUIDS SOMEWHAT DIFFERENT FROM THE USUAL MIL-L-15017A FLUID.

4.3 SPECIAL TESTS. BECAUSE THESE FLUIDS WERE DIFFERENT FROM THE USUAL MIL-L-15017A HYDRAULIC FLUID, IT WAS CONSIDERED PROPER TO EXAMINE THEM MORE THOROUGHLY THAN FOR MERE CONFORMANCE TO THE REQUIREMENTS OF THAT SPECIFICATION. FLUIDS B, C, AND D WERE EXAMINED IN THEIR AS-RECEIVED CONDITION. IN ADDITION, FLUID B ALSO WAS EXAMINED AFTER EMULSIFICATION WITH WATER. A SUMMARY OF THE PROPERTIES INVESTIGATED AND THE METHODS USED IS GIVEN IN TABLE 3.

TABLE 3
ADDITIONAL PROPERTIES INVESTIGATED

PROPERTY	METHOD
OXIDATION STABILITY	(A) ASTM D943 AT 203 F (B) ASTM D943 AT 150 F (TO SIMULATE SERVICE TEMPERATURES)
EFFECT ON ELASTOMERS	FTM791 METHOD 3603.2 USING BUNA N RUBBER (THE ELASTOMER USED IN FLEET HYDRAULIC SYSTEMS WITH PETROLEUM-BASE FLUIDS)
EFFECT ON METALS	MIL-H-19457 (SEE ALSO IMO PUMP RUN 4)
FOAMING CHARACTERISTICS UNDER PRESSURE	SEE APPENDIX B
BULK MODULUS OF EMULSIONS	ULTRASONIC SOUND SPEED METHOD OUTLINED IN APPENDIX B
VISCOSITY OF EMULSIONS	ASTM D88, D445, AND D446
STABILITY OF EMULSIONS TO TEMPERATURE CYCLING	SEE APPENDIX B

THE FIRST THREE TESTS WERE MADE ON FLUIDS AS-RECEIVED. ONLY FLUIDS B AND C AND EMULSIONS OF FLUID B WERE RATED ON FOAMING CHARACTERISTICS. IN THE LAST THREE TESTS, PROPERTIES OF EMULSIONS OF FLUID B ONLY WERE STUDIED. THE RESULTS, GIVEN IN APPENDIX B, SHOW THAT ALL FLUIDS AS-RECEIVED WERE COMPARABLE TO MS 2110-H HYDRAULIC OIL IN OXIDATION STABILITY, EFFECT ON ELASTOMERS AND SYSTEM METALS, AND FOAMING CHARACTERISTICS UNDER PRESSURE (FLUID D NOT TESTED FOR LAST PROPERTY). EMULSIONS OF FLUID B ALSO HAD FOAM-COLLAPSE PROPERTIES COMPARABLE TO MS 2110-H SEA-WATER MIXTURES. BULK MODULI OF EMULSIONS OF FLUID B WERE INTERMEDIATE BETWEEN THOSE OF OIL AND WATER ALONE. THE VISCOSITY OF FLUID B EMULSIONS INCREASED WITH INCREASING WATER CONTENT. FLUID B EMULSIONS WERE STABLE TO TEMPERATURE CYCLING FROM AMBIENT (70-90 F) TO 0 OR TO 50 F. WHEN CYCLED BETWEEN AMBIENT AND 150 F, FLUID B EMULSIONS SEPARATED INTO TWO EMULSIONS, ONE RICH IN OIL AND THE OTHER RICH IN WATER; BUT NO SEPARATE WATER LAYER FORMED.

4.4 CANDIDATE FLUIDS FOR PUMP TESTS. AFTER THE RESULTS OF ALL LABORATORY SCREENING TESTS REPORTED ABOVE HAD BEEN REVIEWED, FLUIDS B, C, AND D WERE CONSIDERED CANDIDATES FOR FURTHER EVALUATION IN PUMP TESTS.

5.0 PUMP TESTS

5.1 PESCO PUMP TESTS. PRELIMINARY PUMP TESTS WERE MADE ON FLUIDS B, C, AND D MIXED WITH UP TO 10% SEAWATER IN A PESCO GEAR PUMP, MODEL IP-349-P-4, CITED IN VARIOUS HYDRAULIC FLUID SPECIFICATIONS AS A SHEAR STABILITY TEST APPARATUS PUMP. IN ALL TESTS IN THIS PUMP, A 1-GAL SAMPLE OF TEST FLUID WAS CIRCULATED AT 3.3 GPM, 140 F, AND 1000 PSI PUMP OUTLET PRESSURE FOR 50 HR. THE SYSTEM CONSISTED OF THE PUMP DISCHARGING THROUGH A RELIEF VALVE TO A SMALL THERMOSTAT-CONTROLLED HEAT EXCHANGER AND SUMP. WEIGHT LOSSES OF THE TWO STEEL GEARS AND FOUR BRONZE BUSHINGS IN THE PUMP WERE USED AS THE CRITERIA OF FLUID PERFORMANCE. A SUMMARY OF THE RESULTS IS GIVEN IN TABLE 4, TOGETHER WITH COMPARABLE DATA ON A QUALIFIED MS 2110-H LUBRICATING OIL.

5.1.1 THE RESULTS SHOW THAT FLUID B ALLOWED ONLY NEGLIGIBLE WEAR OF EITHER STEEL OR BRONZE PARTS WITH FROM 0 TO 10% SEA-WATER CONTAMINATION. FLUID D WITH 10 VOL. PERCENT SEAWATER PERFORMED NEARLY AS WELL AS FLUID B SIMILARLY CONTAMINATED AND BETTER THAN MS 2110-H OIL WITH ONLY 1 VOL. PERCENT SEAWATER. MS 2110-H FLUID, ON THE OTHER HAND, PERFORMED WORST AT ALL CONTAMINATION LEVELS AND WITH CATASTROPHIC RESULTS IN 10% AQUEOUS CHROMATE. FLUID C WAS NO BETTER THAN THE MS 2110-H FLUID AT 1% SEA-WATER CONTAMINATION, BUT, AT 10% SEA-WATER CONTAMINATION, WAS FAR SUPERIOR TO THE MS 2110-H FLUID CONTAINING 10% SODIUM CHROMATE SOLUTION. (IT IS CONSIDERED THAT THE PERFORMANCE OF THE MS 2110-H FLUID WOULD HAVE BEEN EVEN POORER WITH SEAWATER RATHER THAN CHROMATE SOLUTION BECAUSE OF THE CORROSIVENESS OF THE SEAWATER.)

TABLE 4
50-HR PESCO PUMP TEST RESULTS - EMULSIFIABLE FLUIDS

Fluid	Parts Weighed	Average Weight Loss of Parts, mg, After Test in Fluid Containing		
		0% Seawater	1% Seawater	10% Seawater
MS 2110-H (Control)	Two steel gears	7	18	175*
	Four bronze bushings	8	20	over 1000*
B	Two steel gears	4	3	3
	Four bronze bushings	5	2	2
C	Two steel gears	9	42	48
	Four bronze bushings	25	20	23
D	Two steel gears	-	-	13
	Four bronze bushings	-	-	7

*In this run, 10 vol. percent of aqueous sodium chromate (22 1/2% K_2CrO_4) was used instead of seawater. This run was made early in the program in connection with the interim chromate work and was not repeated with seawater because of catastrophic results here.

Photographs of pump parts emphasize the superior operation of the candidate fluids. Figure 1 shows a general view of new parts used in these measurements, and Figure 2 shows photomacrographs of new mating gear and bushing surfaces. Figure 3 shows little damage to similar surfaces after 50 hr in Fluid D + 10% seawater. Figure 4 shows the extent of damage to such surfaces with only 1% seawater using MS 2110-H fluid.

FIGURE 1
NEW PESCO GEARS AND BUSHINGS

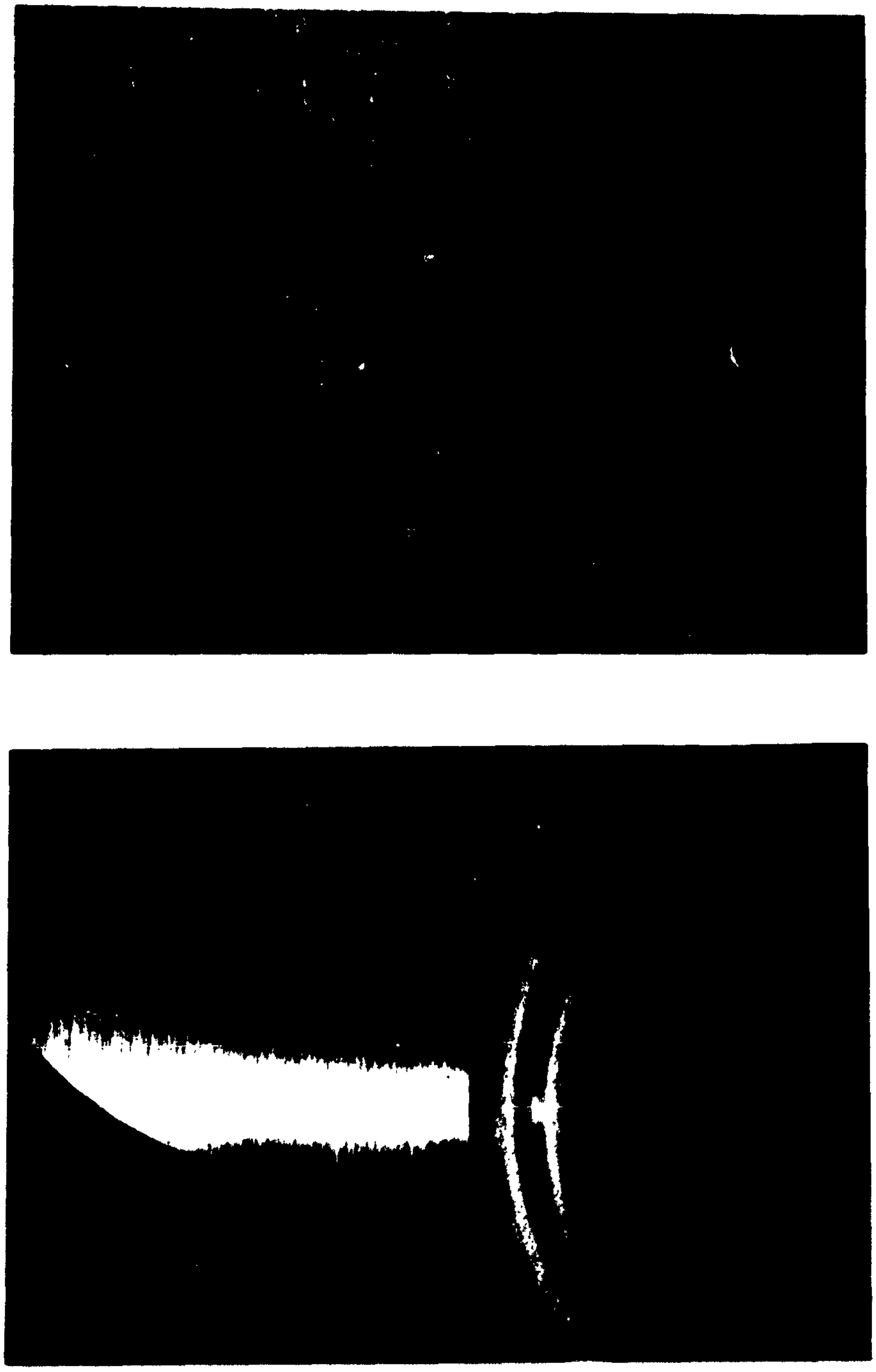

FIGURE 2
NEW PESCO GEAR AND BUSHING MATING SURFACES
(PHOTOMACROGRAPHS)

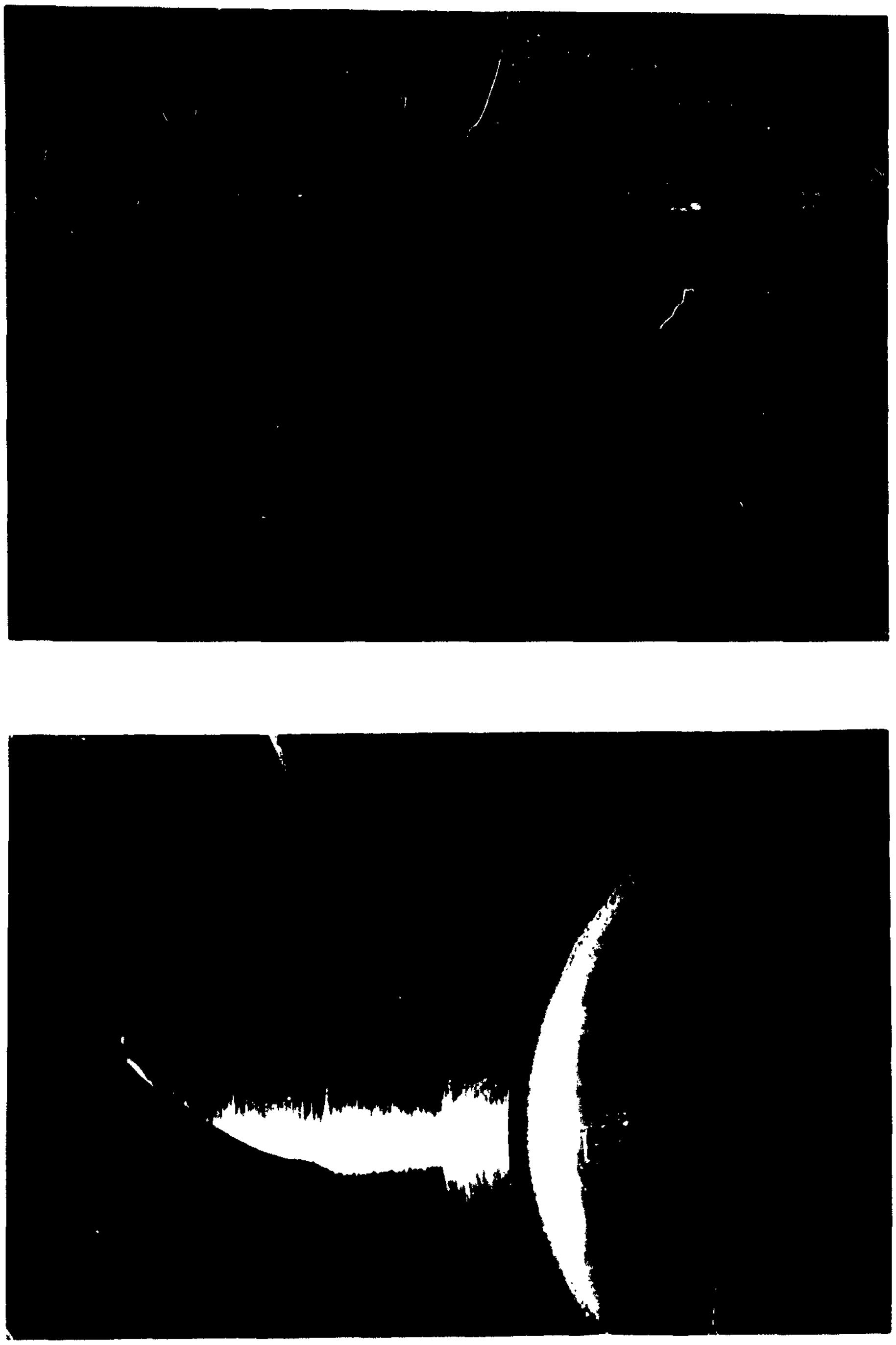

FIGURE 3
PESCO GEAR AND BUSHING MATING SURFACES AFTER 50 HR IN FLUID D WITH 10% SEAWATER
(PHOTOMACROGRAPHS)

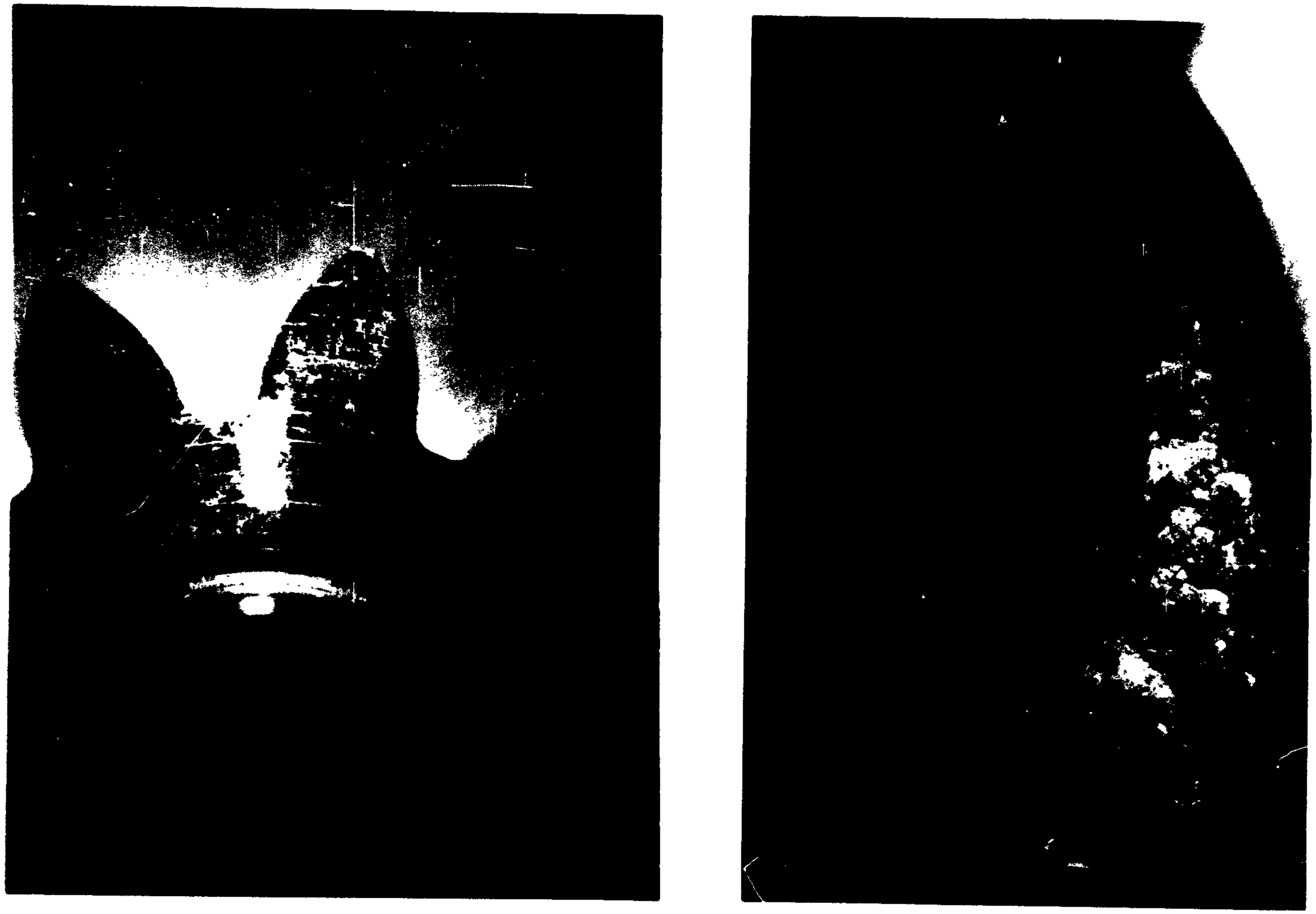

FIGURE 4
PESCO GEAR AND BUSHING MATING SURFACES AFTER 50 HR IN MS 2110-H OIL WITH 1% SEAWATER
(PHOTOMACROGRAPHS)

5.1.2 BECAUSE OF THE ALKALINE REACTION OF FLUID D, THE EFFECT OF ITS EMULSIONS ON SYSTEM METALS, PARTICULARLY ALUMINUM, WAS EXAMINED. SPECIMENS 1 x 2 x 1/4 IN. OF ALUMINUM, COPPER, LOW CARBON AND STAINLESS STEELS, BRASS, MANGANESE AND ALUMINUM BRONZES, AND BABBITT WERE SANDED, WEIGHED, BOLTED TOGETHER WITH SPACERS FOR GOOD ELECTRICAL AND INTIMATE FLUID CONTACT, AND EXPOSED TO THE FLUID DURING THE 50-HR PUMP TEST. THE WEIGHT LOSS OF ALUMINUM WAS 0.01 MG PER CM^2 AND RANGED FROM 0.02 TO 0.06 MG PER CM^2 FOR THE OTHER METALS AND ALLOYS. THESE DATA COMPARE FAVORABLY WITH THE 0.2 MG PER CM^2 MAXIMUM ALLOWED IN MIL-H-19457 FOR METAL ATTACK BY FIRE-RESISTANT HYDRAULIC FLUIDS IN A 7-DAY STATIC STORAGE TEST AT 130 F.

5.1.3 BECAUSE OF THE SUPERIOR RESULTS OBTAINED IN BOTH BENCH SCALE RUST TESTS AND THE SMALL SCALE PUMP TEST, IT WAS DECIDED THAT THE MOST PROMISING TYPE OF FLUID FOR FURTHER EXAMINATION WAS THE EMULSIFIABLE TYPE. ACCORDINGLY, FLUID B, THE FIRST-RECEIVED FLUID OF THIS TYPE, WAS SELECTED AS A PROTOTYPE FOR FURTHER WORK.

5.2 SIMULATED SERVICE TESTS. THE NEXT STAGE IN FLUID EVALUATION WAS FULL SCALE TESTING IN A SUBMARINE-TYPE PUMP TO OBTAIN AN ESTIMATE OF FLUID OPERATIONAL RELIABILITY IN ACTUAL SHIPBOARD EQUIPMENT UNDER SIMULATED SERVICE CONDITIONS. THE PUMP USED WAS A DE LAVAL IMO SCREW-TYPE PUMP, MODEL 31-K-156, SERIAL 509990M, RATED AT 23 GPM, 3000 PSI, 1755 RPM, WITH A BABBITT-LINED STEEL ROTOR HOUSING. THE TEST SYSTEM CONSISTED OF THE PUMP, A PRESSURE RELIEF VALVE, FLOWMETER, SUMP, ASSOCIATED PIPING, AND INSTRUMENTATION. SYSTEM VOLUME WAS 20 GAL. PUMP SUCTION PRESSURE WAS MAINTAINED AT 10 PSI WITH AN AUXILIARY CENTRIFUGAL PUMP. TEMPERATURE WAS REGULATED BY A THERMOSTAT-CONTROLLED HEAT EXCHANGER IN THE PUMP INPUT LINE. FLUID TEMPERATURE AT PUMP OUTLET WAS MAINTAINED BETWEEN 135 TO 150 F. PUMP OUTPUT PRESSURE WAS LIMITED TO 1000 PSI BY MEANS OF THE RELIEF VALVE IN THE FIRST THREE RUNS BECAUSE THIS WAS THE MAXIMUM PRESSURE ALLOWABLE FOR THE TRANSDUCERS USED TO OBTAIN FLUIDBORNE NOISE MEASUREMENTS. PUMP OUTPUT PRESSURE WAS RAISED TO 1800 PSI IN THE LAST RUN TO CONSERVATIVELY SIMULATE THE PRESENT 1500 PSI MAXIMUM EXTERNAL SYSTEM PRESSURE IN SERVICE. OBSERVATIONS WERE MADE TO COLLECT DATA ON AS MANY FACETS OF PUMP OPERATION AS POSSIBLE. THE AREAS OF DATA COLLECTION AND METHOD USED ARE SUMMARIZED IN TABLE 5. A TOTAL OF FOUR RUNS WAS MADE, TWO WITH FLUID B AND TWO WITH A MS 2110-H HYDRAULIC FLUID. THESE LATTER RUNS SERVED AS REFERENCE POINTS FOR COMPARISON OF THE NEW FLUID WITH THE TYPE NOW IN SERVICE. RUN 1A WAS MADE TO OBTAIN BASE LINE DATA ON THE NOISE CHARACTERISTICS OF MS 2110-H OIL. THIS RUN WAS CAUTIOUSLY EXPANDED TO INCLUDE 50-HR RUNS WITH ADDITION OF 1 VOL. PERCENT AQUEOUS CHROMATE (RUN 1B) AND THEN WITH AN ADDITIONAL 1 VOL. PERCENT SEAWATER (RUN 1C). WHEN THE PUMP WAS DISASSEMBLED AFTER THIS WORK, CORROSION WAS NOTED ON THE BEARING BLOCK. NOISE DATA COLLECTION WAS THEN INTERRUPTED TO CHECK THIS POINT WITH A NEW BEARING BLOCK IN RUN 2B AFTER AN INITIAL 50-HR BREAK-IN (RUN 2A). IN RUN 3, FLUID B AND ITS SEA-WATER EMULSIONS WERE TESTED TO OBTAIN NOISE DATA COMPARABLE TO THOSE TAKEN IN RUN 1.

TABLE 5
AREAS OF INVESTIGATION IN SIMULATED SERVICE TESTS

AREA	METHOD OF INVESTIGATION
NOISE GENERATION	TRANSDUCERS TO MEASURE FLUIDBORNE, AIRBORNE, AND STRUCTUREBORNE NOISE
CORROSION	EXAMINATION OF STATIC AND DYNAMIC SURFACES OF PUMP PARTS EXPOSED TO THE FLUID, ESPECIALLY OF THE BEARING BLOCK, ROTORS, AND SUMP
WEAR	MEASUREMENT OF CRITICAL DIMENSIONS OF WORMS AND ROTOR HOUSING
FILTER CLOGGING	PRESSURE DROP ACROSS FILTER
EFFECT ON SYSTEM METALS	REPRESENTATIVE METAL SPECIMENS WERE EXPOSED TO THE TEST FLUID

THIS RUN WAS BEGUN USING FLUID B AS-RECEIVED (RUN 3A), THEN CONTINUED WITH 2, 5, AND 10% SEAWATER (RUNS 3A, 3B, AND 3C, RESPECTIVELY) TO OBTAIN 250 HR OF OPERATION ON FLUID B + 10 VOL. PERCENT SEAWATER IN RUN 3C. MEASUREMENTS OF WEAR, FILTER CLOGGING, AND CORROSION WERE ALSO TAKEN. RUN 4 WAS A 1000-HR TEST OF FLUID B CONTAINING 10 VOL. PERCENT SEA-WATER CONTAMINATION. THE RUN WAS INTERRUPTED AFTER 500 HR (RUN 4A) TO EXAMINE THE INTERIOR CONDITION OF THE PUMP AND THEN WAS CONTINUED FOR A TOTAL OF 1000 HR OF OPERATION IN RUN 4B. THE PURPOSE OF RUN 4 WAS TO OBTAIN ENDURANCE RELIABILITY DATA ON OPERATION OF FLUID B CONTAMINATED WITH SEAWATER. THIS RUN WAS SIMILAR TO RUN 3 EXCEPT THAT THE PUMP WAS OPERATED INTERMITTENTLY TO MORE NEARLY SIMULATE THE IRREGULAR OPERATION-OR-SECURED CONDITION OF SHIPBOARD SERVICE. UNLIKE RUNS 1 TO 3 WHICH WERE OPERATED CONTINUOUSLY, IN RUN 4 THE PUMP WAS SHUT DOWN FROM 0000 HOURS EACH NIGHT TO 0800 EACH MORNING, MONDAY THROUGH FRIDAY. THIS SIMULATES THE MOST SEVERE RUSTING CONDITIONS, WHEN THE RUST INHIBITOR FILM CANNOT BE REPLENISHED BY BULK FLUID CIRCULATION. IN ALL FOUR RUNS, A 20-GAL OIL SAMPLE CHARGE WAS USED, PUMP OUTLET TEMPERATURE WAS MAINTAINED BETWEEN 140 TO 160 F AS REQUESTED IN REFERENCE (K), AND FLOW RATE WAS MAINTAINED BETWEEN 20 AND 25 GPM. OUTLET PRESSURE IN RUNS 1 TO 3, INCLUSIVE, WAS 1000 PSI, BEING LIMITED TO THE MAXIMUM ALLOWABLE PRESSURE FOR THE FLUIDBORNE-NOISE PICKUP TRANSDUCER.

Outlet pressure was raised to 1800 psi in Run 4 to conservatively simulate the present 1500 psi maximum system pressure in service.

The data collected in these runs are presented in four appendixes. The first of these, Appendix C, shows data collected during pump operation, such as the nature of the fluid being tested, hours of operation, temperature, flow rate, and filter pressure drop. Appendix D summarizes data collected in studying noise characteristics, Appendix E shows wear data of various pump parts, and Appendix F gives weight losses of metals exposed to Fluid B in Run 4.

5.3 Noise Measurements. Measurements of structureborne, fluid-borne, and airborne noise were made on base fluids and sea-water emulsions of MS 2110-H and Fluid B. The results and details of measurements are shown in Appendix D. As expected, the primary noise output occurred at frequencies corresponding to the rotational speed of the pump and its harmonics. All noise levels showed no significant change between base fluids or between them and their emulsions. Thus, no noise problems should be expected in Fleet use of Fluid B.

5.4 Wear of Pump Rotors. The data in Appendix E show that wear was negligible on both power and idler rotors in all runs. Figure 5 shows the new parts used in Run 4 and gives a view of the rotating parts that were measured to obtain these data. Representative photomacrographs of the outer surface of the power worm before and after Run 4 (Figures 6 and 7) show no evidence of wear after exposure to a 10% sea-water emulsion of Fluid B for 1000 hr of operation.

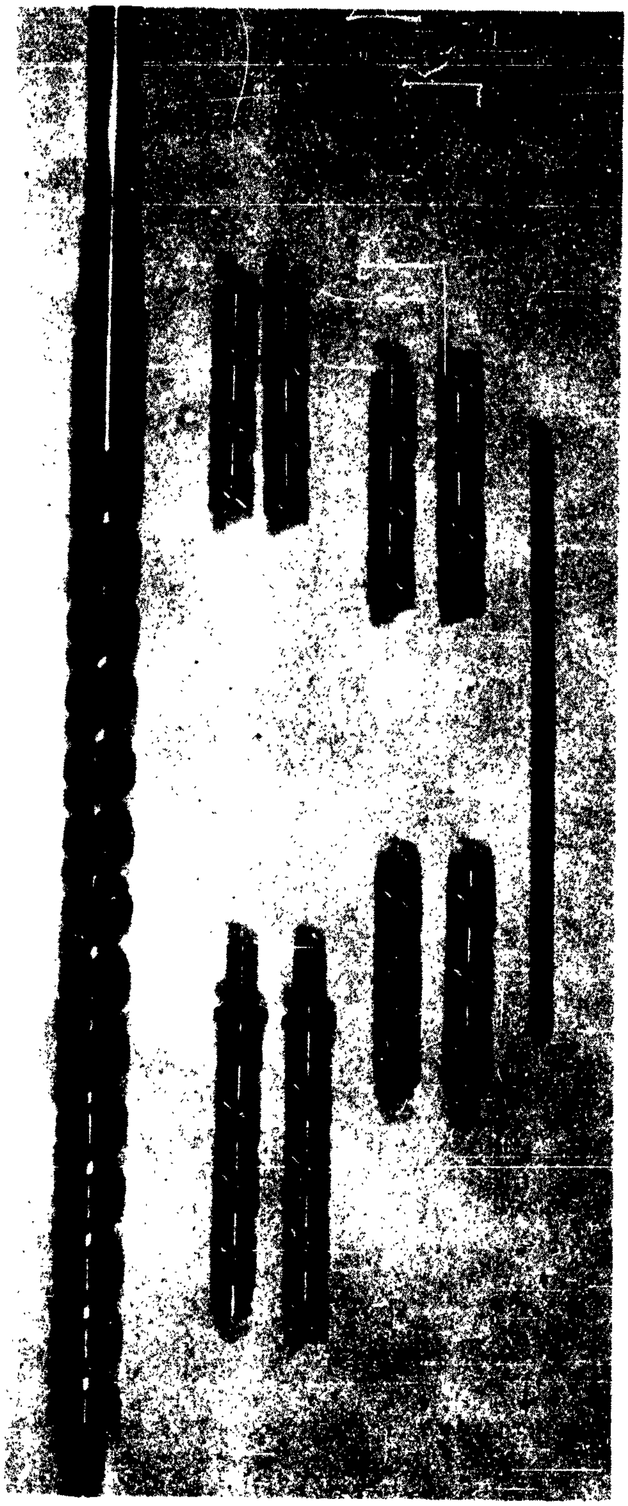

FIGURE 5

IMO PUMP ROTORS - GENERAL VIEW

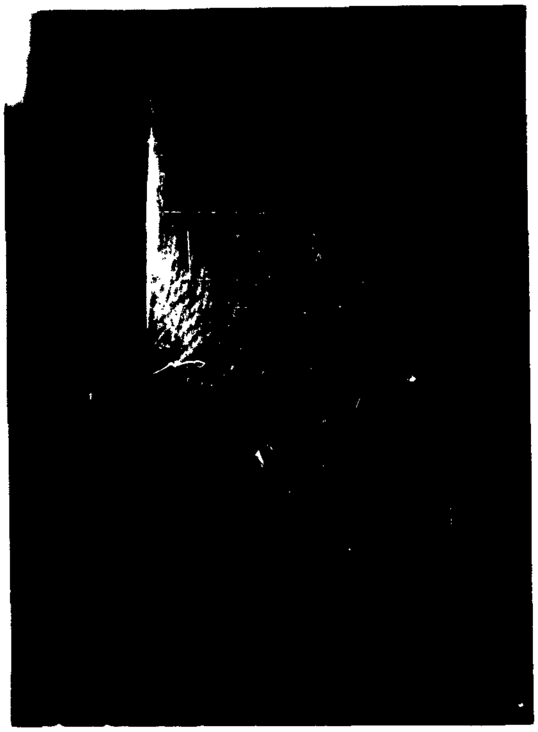

FIGURE 6
IMP POWER ROTOR OUTER SURFACE
BEFORE RUN 4
(PHOTOMACROGRAPH)

FIGURE 7
IMP POWER ROTOR OUTER SURFACE
AFTER RUN 4
(SAME POSITION AS FIGURE 6)
(PHOTOMACROGRAPH)

5.5 Wear of Pump Barrel. Visual inspection of the barrel after the first 500 hr of operation (end of Run 4A) showed no evidence of damage; therefore, no measurements were made. However, after 1000 hr of operation (end of Run 4B), visual inspection revealed small areas where babbitt had been wiped. A photograph of the affected area in the right idler barrel of the suction end section is shown in Figure 8. Diameter measurements then were taken. Changes between these and original values are shown in Appendix E. Diameter increases in excess of 1 mil were found in the suction and center sections of the right idler barrel. The affected areas occurred on surfaces under radial thrust load from the idlers. The cause of the wiping of these small areas has not been determined. No unusual local overheating was noticed. Measurements of the longitudinal axis of the idlers showed no nonlinearity or "bowing." If poor lubricity was responsible, wiping might be expected in the high-pressure discharge section rather than the suction end. No pressure drop, loss of output capacity, or excessive noise was noted during any part of the 1000 hr of operation, and pump operation at the time of shutdown was considered satisfactory.

5.6 Condition of Filters. The pressure drop across the 5-μ filters increased from about 5 psi with both MS 2110-H and Fluid B to approximately 12 psi when seawater was added to the base fluid. This increase could be due, at least in part, to the known increase in viscosity of the emulsions over those of the base fluids. The pressure drop was greater with emulsions of MS 2110-H fluid. This range of pressure drop is undesirable but not serious, since a 25 psi pressure drop is allowed before filter-cartridge replacement is necessary. The pressure drops remained approximately constant through the runs, indicating there was little further buildup of debris. After disassembly, however, the filters used in Runs 1 and 2 were heavily coated with a yellow sludge. Figure 9 shows the filters from Run 2 after 286 hr. Spectrographic analysis showed the major constituents were sodium and chromium (as expected), plus iron. Figure 10 shows that a similar filter after 1000 hr in Run 4 had considerably less debris. Less accumulation of sludge thus occurred with Fluid B.

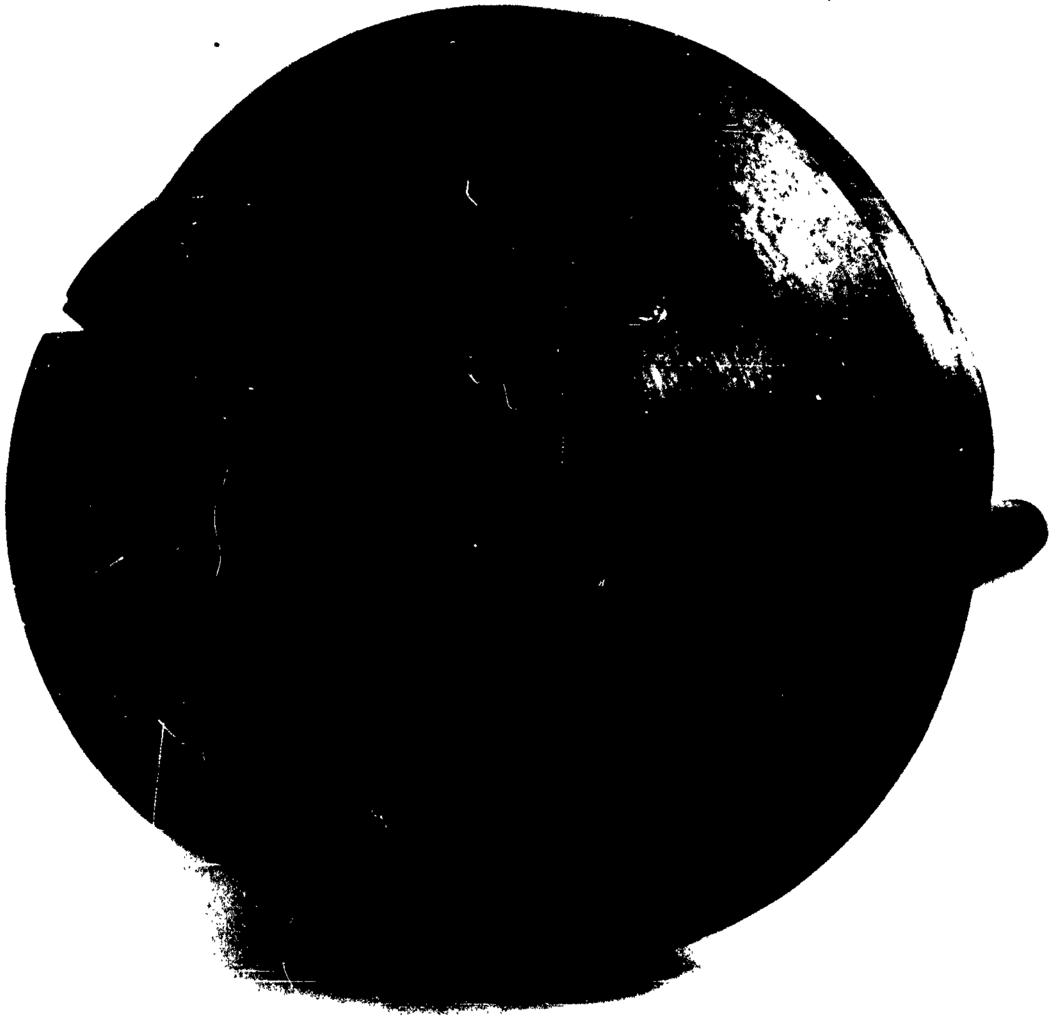

FIGURE 8
IMO PUMP BARREL AFTER RUN 4
SUCTION END SECTION, POWER END FORWARD

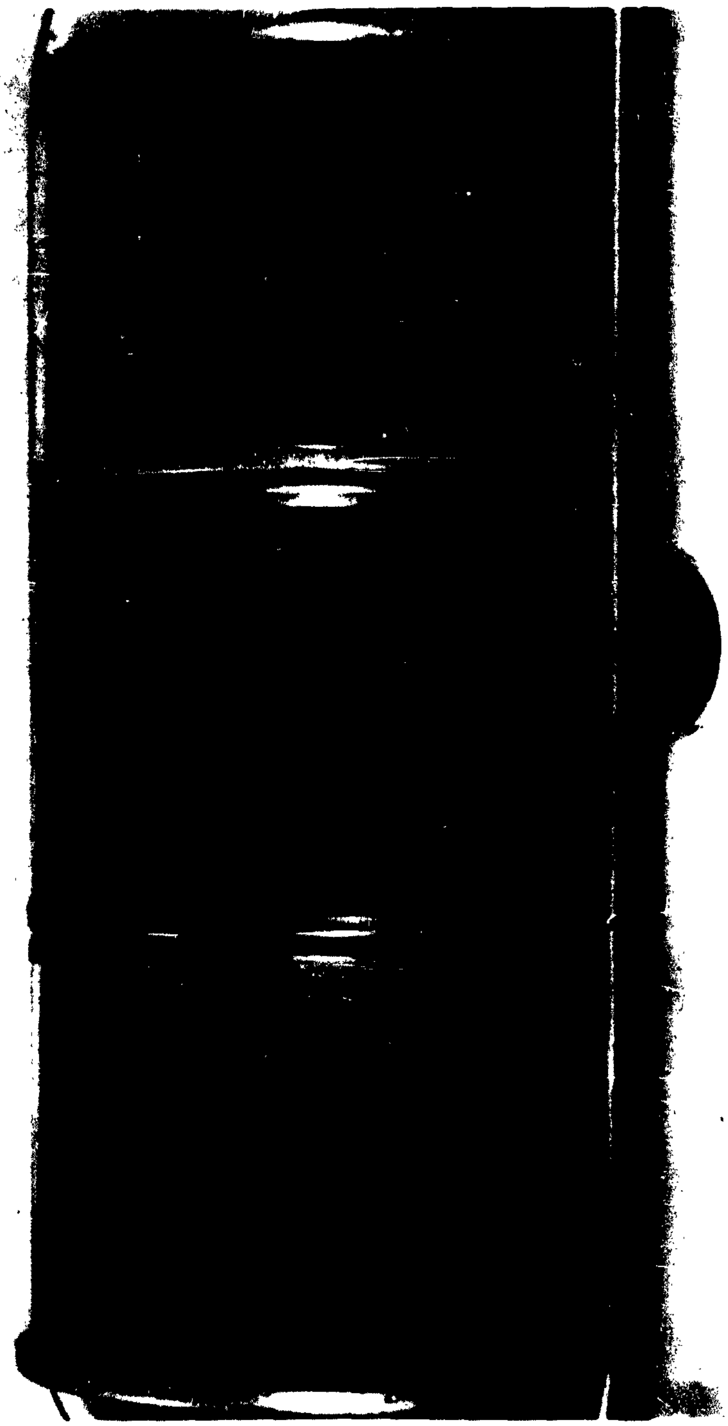

FIGURE 9
IMO FILTER ELEMENTS AFTER RUN 2

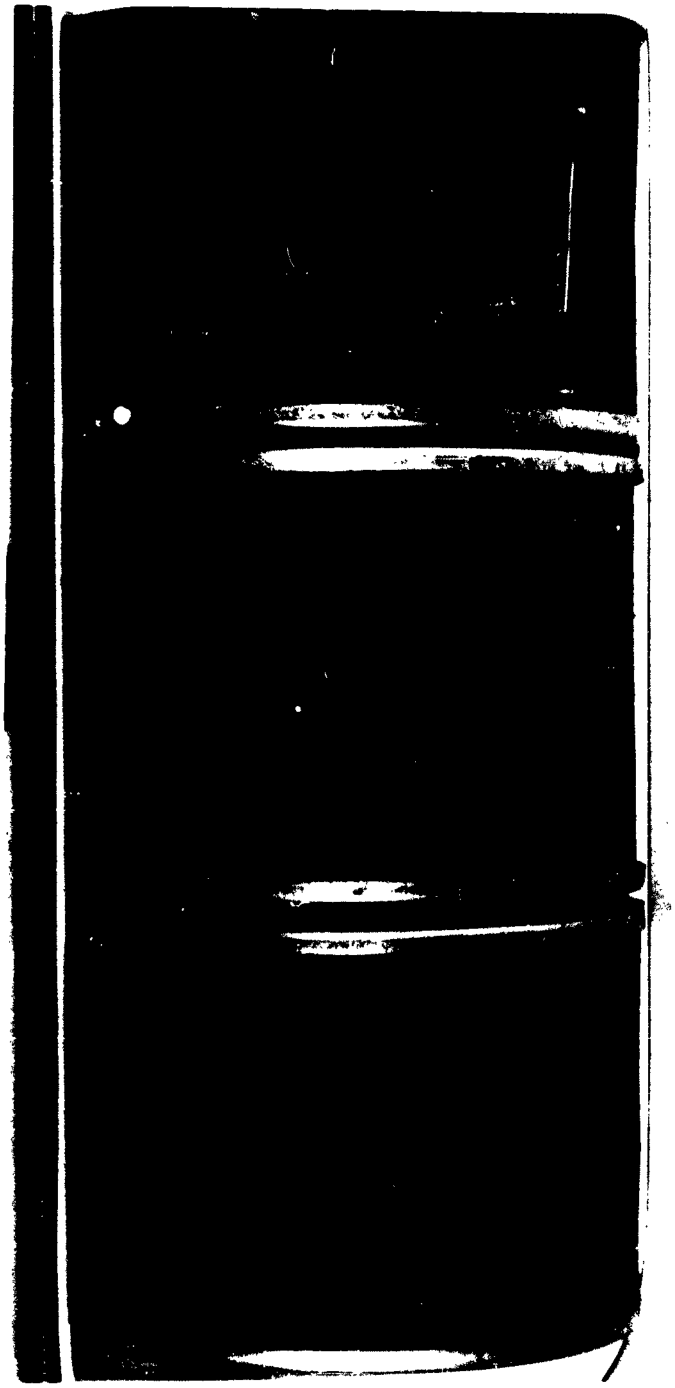

FIGURE 10
IMO FILTER ELEMENTS AFTER RUN 4

5.7 Corrosion. The bearing block corrosion noted in Run 1 with MS 2110-H fluid caused particular concern because it showed the ineffectiveness of aqueous chromate, even with as high as 1:1 volume ratio with seawater. Figure 11 shows that the outer surface of a new bearing used in Repeat Run 2 was pitted over the entire surface with large areas of loosely adhering rust near the outboard end cap joint. X-ray diffraction identified Fe_3O_4 as the major constituent. Figures 12 and 13 show a new bearing block before and after 1000 hr of exposure in Run 4 to Fluid B contaminated with 10 vol. percent seawater. Comparison shows the original polish marks are still visible in Figure 13 with no evidence of rust. Thus, Fluid B showed considerable improvement over presently used fluids in protecting the polished bearing block surface from rust.

5.7.1 The weight changes of the bronze bushings, given in Appendix E, can be used as a measure of the possible effect of the fluid on bronze. For example, the center bushing weight loss in Run 4 of 317 mg per 1000 hr calculates to 1.45 mils per year penetration rate. This rate is not considered serious.

5.7.2 Where comparison was possible, mating measurements of shaft and bushing diameters in Appendix E indicate that shaft-to-bushing clearances are in the same order of magnitude for MS 2110-H in Runs 1 and 2 as for Fluid B in the much longer Run 4. In summary, metal losses, though easily detectable, are considered to be of insufficient magnitude to affect normal service operation. Also, there was no evidence from pump operation data that clearances or wear were excessive.

5.8 Effect on System Metals. In the sump in Run 4, a total of ten ferrous and nonferrous metal specimens, representing a variety of hydraulic system metals, were exposed to emulsions of Fluid B with seawater. The ferrous alloys were mild steel, cast iron, and stainless steel. Nonferrous alloys were copper-nickel, nickel-copper, naval brass, admiralty brass, and aluminum-bronze. Metallic copper and aluminum specimens also were included. One specimen of each metal was submerged in the fluid, one was exposed in the vapor space above the fluid, and one was half exposed, half submerged. All specimens were wired together in a rack for good electrical contact. After 1000 hr, the specimens were removed, washed in solvents, dried, and weighed.

5.8.1 Results. Appendix F shows that there was little, if any, attack on aluminum or ferrous metal and nickel alloys. However, there is more activity (weight loss) with copper and brass. The significance of this would have to be shown by comparable runs on contaminated MS 2110-H oil. If, however, it is assumed that this rate of attack is linear with time and that the system operated continuously in 10% seawater, the penetration rate for copper calculates to 0.35 mil per year, and somewhat less for naval or admiralty brass.

5.8.2 Vapor Space Rust Protection. Corrosion in the air space in the sump occurred with emulsions of both MS 2110-H and Fluid B. This was to be expected, since neither fluid contained vapor phase corrosion inhibitors. However, the effectiveness of a simple cooling coil to control this corrosion is shown in Figure 14. This photograph of the sump was taken immediately after completion of Run 4 and drainage of fluid. A cooling coil was installed on the left side of the central baffle plate, just above the fluid level, to minimize water vapor loss and consequent condensations on the cooler sump walls. In the right side of the sump, where no cooling coil was installed, there was water condensation and sump corrosion in the vapor space.

5.9 Properties of Used Fluid B - Run 4. After the 1000-hr service test, the 10 vol. percent sea-water emulsion of Fluid B was examined for any significant changes in properties. Results are given in Table 6 below together with similar data taken at the beginning of Run 4.

Table 6
Properties of the Fluid

Property	At Start	After 1000 Hr
Viscosity, SSU, 130 F	125	134
Reaction	Neutral	Neutral
Acid No.	0.79	0.78
Precipitation No.	None*	None*
Spectrographic Analysis for Wear Metals, ppm:		
Copper	0.1	12
Iron	0.5	28
Lead	<0.1	11

*Seawater remained emulsified; no solids.

The results show there was practically no change in the fluid except for buildup of wear metals. The copper content of the fluid is associated with weight losses of the pump bushings and copper bearing metal specimens; the lead probably accumulated from wear of the babbitt lining of the pump barrel, and iron from oxidation and wear of ferrous parts of the system.

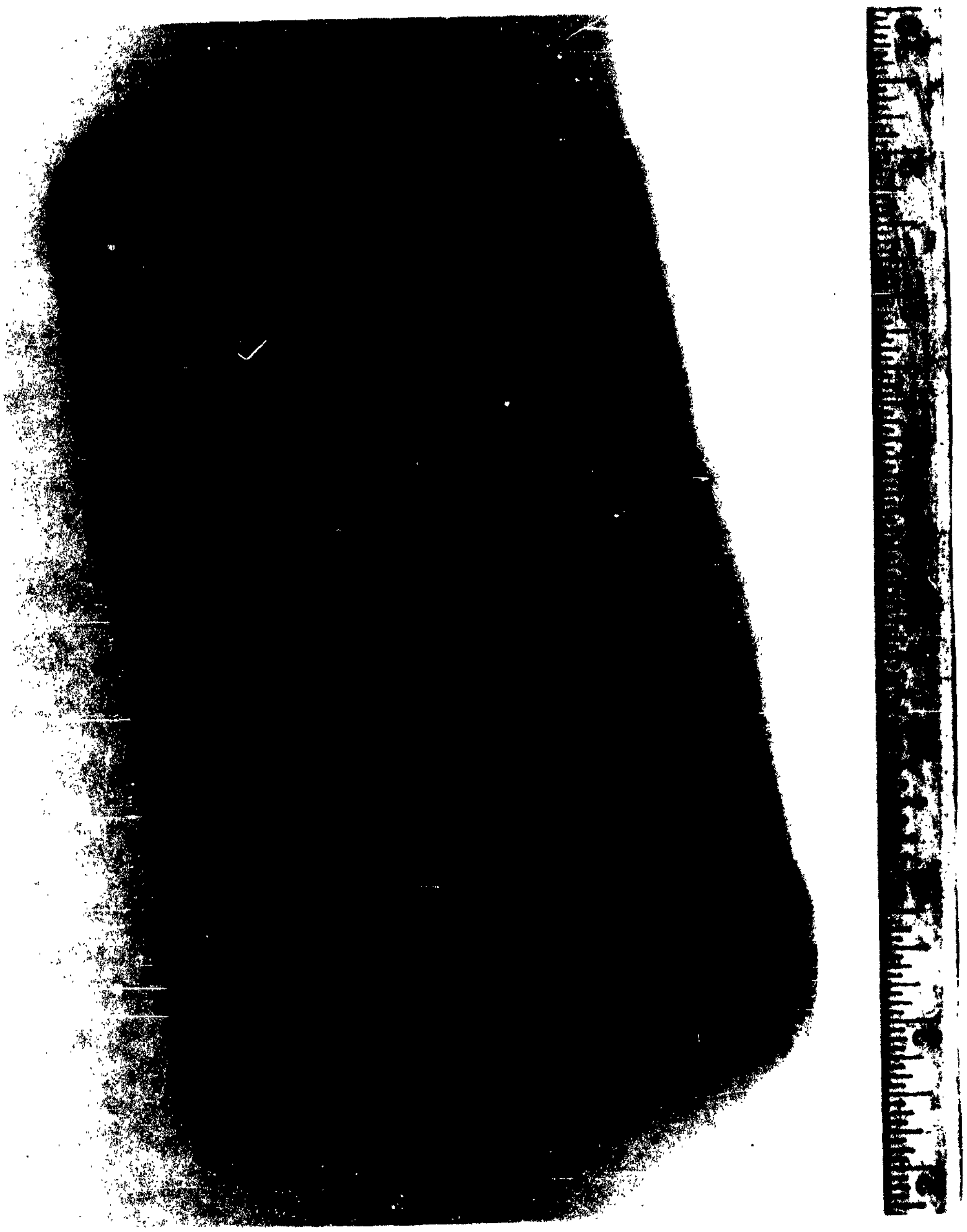

FIGURE 11
IMO BEARING BLOCK AFTER RUN 2

FIGURE 12
IMO BEARING BLOCK BEFORE RUN 4

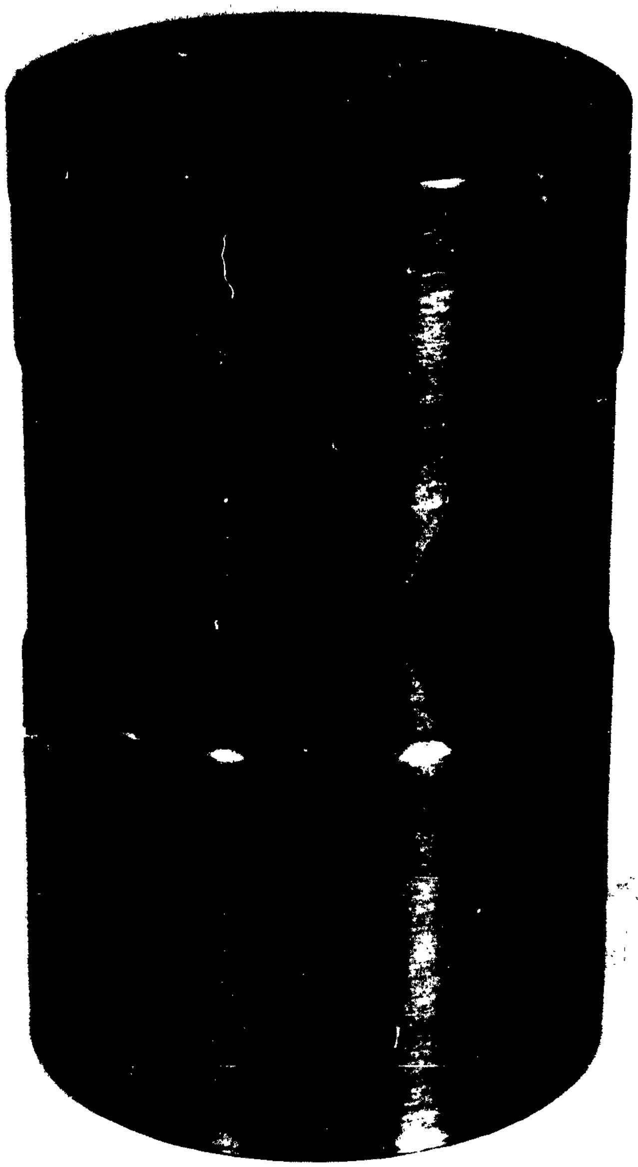

FIGURE 13
IMO BEARING BLOCK AFTER RUN 4
(SAME POSITION AS FIGURE 12)

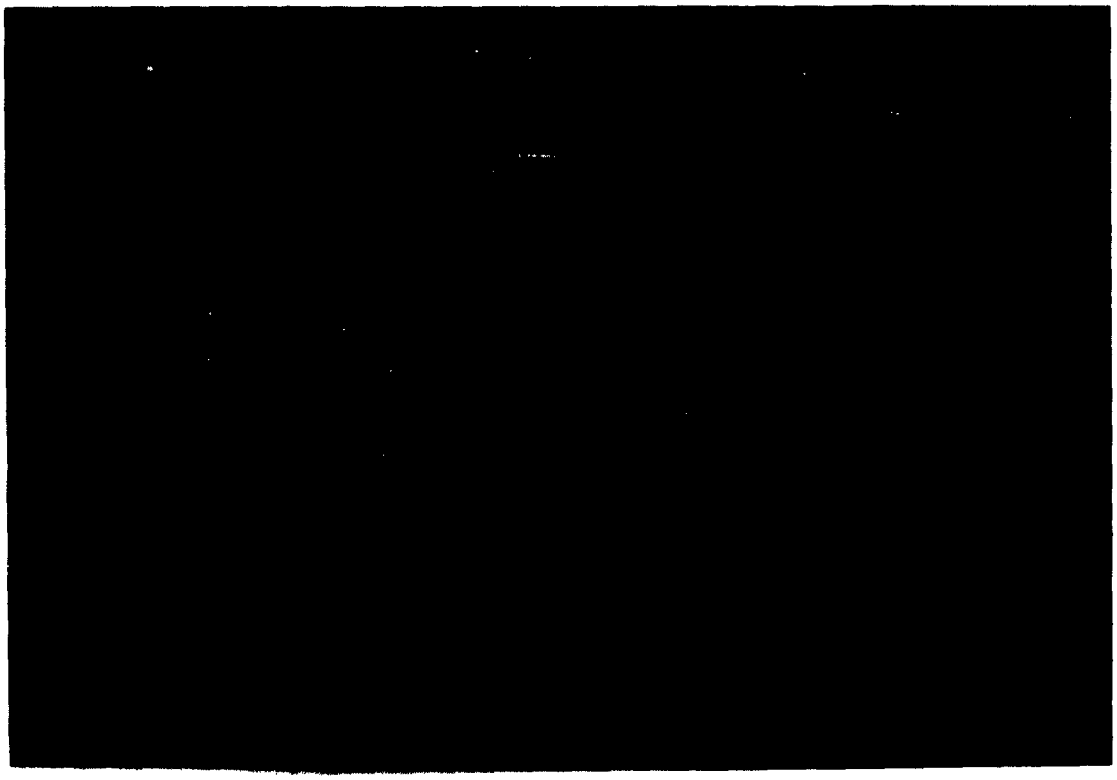

FIGURE 14
IMO SUMP AFTER RUN 4

5.10 <u>Summary of Full Scale Pump Tests</u>. Fluid B performed adequately in the full scale pump circuit when contaminated with 10% seawater. There were no harmful effects on packing and gasket materials and no increase in noise level. The contaminated fluid did not damage or cause excessive pressure drop across the standard 5-μ filters in the system. Corrosion of ferrous pump parts was eliminated. Pump wear in 1000 hr of operation was not enough to affect the pump's performance. There was some corrosion of copper alloys in the pump and a small wiped area in the babbitt lining of the pump housing. Also, rusting in the air space in the fluid sump was not reduced by this fluid. These results are in sharp contrast to the poor performance of MS 2110-H fluid contaminated with only 1% seawater. The performance of Fluid B in this critical experiment was so good that it was decided that full scale pump tests of non-emulsifying Fluid C would not be necessary.

6.0 DISCUSSION

The information presented above indicates that it is possible to upgrade considerably the rust-inhibiting ability of submarine hydraulic fluids. One method would be to use nonemulsifying Fluid C, which was considerably better in bench rust tests than currently used fluids. However, the improvement was not nearly so great in the small scale pump test. Therefore, the degree of improvement to be obtained in actual service is somewhat problematical. The second method, use of a fluid that is permitted to emulsify freely with contaminating water, has been shown, insofar as possible in laboratory bench and full scale pump tests, to provide a considerable increase in rust inhibition without any undesirable side effects. This method therefore appears to be the preferable one. Since the use of emulsifying fluids represents a departure from present practice, a shipboard trial appears in order before the fluid is put into general Fleet use. Instructions to remove contaminated fluids from systems at first opportunity should remain in force. While the work reported here has dealt with improved fluids of only one viscosity level, the nature of the improvements is not to be associated with any particular viscosity level. Therefore, it should be possible to extend the scope of the improvements made to other viscosity level fluids, without repeating the extensive investigations reported here. If the proposed Fleet trial of emulsifiable fluid is successful, a new specification for its procurement will be required. The technical requirements of the proposed specification for this fluid are outlined in Appendix G.

7.0 CONCLUSIONS

Both emulsifiable and nonemulsifiable petroleum-base fluids have been found superior to approved MIL-L-15017A fluids for use as a submarine hydraulic system fluid for rust protection

AGAINST SEA-WATER CONTAMINATION. CONCOMITANT PROPERTIES OF A SATISFACTORY HYDRAULIC FLUID FOR THIS APPLICATION, SUCH AS OXIDATION STABILITY, BULK MODULUS, FOAMING TENDENCY, AND EFFECT ON SYSTEM ELASTOMERS AND METALS, HAVE NOT BEEN COMPROMISED. THE EMULSIFIABLE FLUID, WHICH GAVE THE BETTER RUST PROTECTION IN SMALL SCALE TESTS, PERFORMED WELL IN FULL SCALE LABORATORY PUMP TESTS. A SHIPBOARD TRIAL OF THIS FLUID IS CONSIDERED TO BE JUSTIFIED.

8.0 FUTURE ACTION

A COPY OF THIS REPORT WILL BE FORWARDED TO SUBMARINE HYDRAULIC PUMP MANUFACTURERS AND TO EACH SUPPLIER OF MATERIALS IN THIS INVESTIGATION AS WELL AS TO OIL SUPPLIERS LISTED ON THE QUALIFIED PRODUCTS LIST OF MS 2110-H GRADE HYDRAULIC OIL OF MILITARY SPECIFICATION MIL-L-15017A TO OBTAIN REVIEW OF THE PROPOSED CHANGES IN APPENDIX G AND TO INSURE DEVELOPMENT OF ADEQUATE SUPPLIES OF IMPROVED PETROLEUM-BASE HYDRAULIC FLUIDS.

REFERENCES

(A) NAVENGRXSTA CONF REPT 95 680B OF 25 APR 1962
(B) COMSUBPAC LTR FF 4-11:RRC 9210 SER 40/4045 OF 21 SEP 1960
(C) COMSUBLANT LTR FF 4-12 9210/00 SER 403/6007 OF 8 SEP 1960
(D) BUSHIPS INST SS/9210 SER 632D-1344 OF 3 MAR 1961
(E) BUSHIPS INST SS/9210 SER 632D-171 OF 2 MAR 1962
(F) BUSHIPS LTR R001 07 01 SER 634A-247 OF 11 JUL 1961
(G) BUSHIPS LTR R001 07 01 SER 634A-43 OF 17 FEB 1961
(H) NAVENGRXSTA REPT 95 680C OF 23 AUG 1962
(I) FTM 791A METHOD 5311 OF 31 DEC 1961
(J) ASTM METHOD D665-60
(K) BUSHIPS LTR SER 634A-163 OF 3 APR 1963

APPENDIX A
CHEMICAL AND PHYSICAL TEST RESULTS

	FLUID CODE		
	B	C	D
SPECIFIC GRAVITY AT 60/60 F	0.889	0.875	0.880
AMERICAN PETROLEUM INSTITUTE, DEGREES	27.6	30.2	29.3
FLASH POINT, OPEN CUP, F	375	400	420
POUR POINT, F	-10	-20	-20
VISCOSITY:			
CENTISTOKES AT 0 F (DETERMINED)	2795	2965	2200[1]
CENTISTOKES AT 100 F	41.9	43.7	42.0
CENTISTOKES AT 210 F	5.93	6.07	6.40
VISCOSITY INDEX	91	90	111
COLOR	3.5	2.0	6.0
REACTION	NEUTRAL	NEUTRAL	ALKALINE[2]
ACID NO.	0.88	1.12	-
BASE NO.	-	-	0.53
SAPONIFICATION NO.	2.2	2.3	2.0
PRECIPITATION NO.	NONE	NONE	NONE
CARBON RESIDUE, % (ASH FREE)	0.15	0.01	0.09
ASH, % (50-G SAMPLE)	0.72	<0.01	0.27
ANALYSIS OF ASH: MAJOR CONSTITUENTS	CALCIUM, PHOSPHORUS, SODIUM, ZINC	-	CALCIUM
CORROSION, COPPER STRIP AT 212 F	PASS 1A	PASS 1A	PASS 1A
TOTAL SULFUR, %	0.54	0.10[3]	0.25
WATER, %	0.1	NONE	0.3
RUST PREVENTION, SEAWATER	PASS	PASS	PASS
FOAM TEST, SEQUENCE I, ML FOAM	10	295	330
MIN TO SEPARATE	<1	5	4
EMULSION TEST, MIN TO SEPARATE:			
DISTILLED WATER	[4]	10	[5]
SEAWATER	[4]	30	[4]

[1]EXTRAPOLATED
[2]pH OF WATER WAS 11.5
[3]MANUFACTURER'S DATUM.
[4]COMPLETE EMULSION FOR OVER 24 HR, ONLY SLIGHT OIL SEPARATION AFTER 1 WEEK.
[5]12-ML WATER + 68-ML EMULSION AND NO OIL AFTER 1 HR; 15-ML WATER + 65-ML EMULSION AFTER 24 HR.

APPENDIX B

SPECIAL SCREENING-TEST RESULTS

OXIDATION STABILITY TEST RESULTS[1]

TEMPERATURE F	OIL CODE	OBSERVATIONS AT TERMINATION OF TEST		
		HOURS	NEUT No.	APPEARANCE OF FLUID[2]
203	B	525	2.4	EMULSIFIED
	C	1000	1.2	OIL - BROWN WATER - GREEN
	MS 2110-H CONTROL	675	1.9	OIL - BROWN WATER - GREEN
150	B	2000	2.0	EMULSIFIED
	C	2000	1.0	CUFF OF EMULSION OIL - BROWN WATER - GREEN
	D	2000	0.5	CUFF OF EMULSION OIL - BROWN WATER - GREEN
	MS 2110-H CONTROL	2000	1.2	3- TO 5-ML EMULSION OIL - BROWN WATER - GREEN

[1] METHOD OF ASTM D943.

[2] ALL COPPER COILS WERE SLIGHTLY TARNISHED EXCEPT THAT THE COIL IN FLUID B AT 200 F WAS BLACKENED. ALL STEEL COILS WERE DULL-TO-BRIGHT WITH NO EVIDENCE OF ATTACK.

NEUT - NEUTRALIZATION

EFFECT ON BUNA N ELASTOMER[1]

FLUID CODE	VOLUME INCREASE, %
B	1.0
C	1.6
D	1.9
MS 2110-H CONTROL	1.4

[1]METHOD OF FTM 791 PROCEDURE 3603.2.

EFFECT ON METALS[1]

FLUID CODE	WEIGHT CHANGE (MG PER CM^2) OF:[2]			
	COPPER[3]	BRASS	STEEL	ALUMINUM
B	+0.02	+0.02	+0.04	+0.01
C	+0.03	+0.03	+0.04	+0.01
D	+0.03	+0.02	+0.04	-0.01
MS 2110-H CONTROL	-0.01	+0.01	+0.03	NONE

[1]METHOD OF MIL-H-19457.
[2]+ SIGNIFIES GAIN IN WEIGHT, - SIGNIFIES LOSS.
[3]COPPER SPECIMENS AFTER TEST WERE RATED 1A BY ASTM D130 EXCEPT FOR CONTROL, WHICH RATED 1B.

FOAMING CHARACTERISTICS UNDER PRESSURE

1. METHOD. A 115-ML SAMPLE OF THE TEST FLUID IS PLACED IN A MODIFIED 300-ML SULFUR BOMB OF ASTM METHOD D129. THE BOMB IS MODIFIED BY HAVING A SHORT LENGTH OF 1/8-IN. PIPE AND VALVE INSTALLED IN ITS TOP. FLUID AND BOMB ARE THERMOSTATED FOR 1/2 HR AT TEST TEMPERATURE IN A WATER BATH. THE BOMB IS THEN CHARGED WITH AIR TO THE DESIRED PRESSURE AND TUMBLED AT 5 RPM FOR 1/2 HR AT TEST TEMPERATURE IN THE HYDROLYTIC STABILITY TEST APPARATUS OF MIL-H-19457. THE BOMB IS THEN INVERTED OVER A 500-ML GRADUATED CYLINDER, AND THE 1/8-IN. VALVE IS OPENED. THE INITIAL VOLUME OF FOAM IS OBTAINED AS A MEASURE OF FOAMING TENDENCY. EITHER THE TIME FOR COMPLETE COLLAPSE OF THE FOAM, IF UNDER 10 MIN, OR MILLILITERS OF FOAM AFTER 10 MIN IS RECORDED AS A MEASURE OF FOAM STABILITY.

2. DATA ON FINISHED OILS

TEMPERATURE F	INITIAL PRESSURE PSI	FLUID CODE	OBSERVATIONS	
			INITIAL FOAM ML	COLLAPSE TIME MIN
75	400	B	270	6
		C	220	<1
		MS 2110-H CONTROL	265	3
75	300	B	240	7
		C	230	7
		MS 2110-H CONTROL	230	3
150	300	B	245	3
		C	255	1
		MS 2110-H CONTROL	250	1

3. <u>Data on Emulsions with Seawater</u>

Temperature F	Pressure psi	Fluid Code	Seawater %	Observation, Foam, ml, After: Initial	10 min	3 hr	24 hr
75	400	B	1	250	245	None	-
			5	240	240	None	-
			10	215	215	None	-
			50	170	90	None	-
		MS 2110-H (Control)[1]	1	270	None	-	-
			5	265	145	None	-
			10	270	140	None	-
			50	155	153	50	20
150	300	B	1	220	170	None	-
			5	235	185	None	-
			10	220	200	75	35
			50	215	170	50	40

[1] Since emulsion was unstable, water + oil added separately to bomb to total 115 ml.

BULK MODULUS

1. APPARATUS. A SING-AROUND ULTRASONIC 3-MC VELOCIMETER, SIMILAR TO THAT DESCRIBED IN REFERENCE (1), WAS USED. THE SING-AROUND FREQUENCY WAS MEASURED WITH A HEWLITT-PACKARD MODEL 526 COUNTER.

2. STANDARD. DISTILLED WATER WAS USED AS A STANDARD. DATA FOR SPEED OF SOUND IN DISTILLED WATER, TAKEN FROM REFERENCE (2), WAS 4725.7 FPS AT 80 F.

3. METHOD. APPROXIMATELY 100 ML OF FLUID WAS PLACED IN THE ULTRASONIC CIRCUIT, COMPLETELY COVERING THE TRANSDUCERS. AFTER TEMPERATURE EQUILIBRIUM HAD BEEN ESTABLISHED (10-15 MIN), READINGS OF SING-AROUND FREQUENCY WERE TAKEN UNTIL TEN SUCCESSIVE READINGS DIFFERED BY ±1 CPS. ALL DATA WERE TAKEN AT ATMOSPHERIC PRESSURE AND 80±1 F.

4. FLUIDS TESTED. WATER, PURE FLUID B, AND EMULSIONS OF FLUID B WITH 10 VOL. PERCENT DISTILLED WATER WERE TESTED. FURTHER TESTS WITH EMULSIONS CONTAINING SEAWATER WERE PLANNED BUT WERE CURTAILED DUE TO EQUIPMENT FAILURE.

5. CALCULATION OF SPEED OF SOUND IN TEST FLUID. FROM THE EQUATION DISTANCE = VELOCITY X TIME IS OBTAINED:

$$V_W T_W = V_O T_O$$

OR

$$V_O = (V_W)\ (T_W/T_O)$$

WHERE
V_O = VELOCITY OF SOUND IN OIL.
V_W = VELOCITY OF SOUND IN WATER.
T_O = TIME FOR ONE SING-AROUND CYCLE IN OIL, μSEC PER C.
T_W = TIME FOR ONE SING-AROUND CYCLE IN WATER, μSEC PER C.

T_O AND T_W ARE RECIPROCALS OF THE RESPECTIVE SING-AROUND FREQUENCIES IN OIL AND WATER, MULTIPLIED BY 10^6, TO CONVERT TO MICROSECONDS FOR EASY HANDLING.

6. DETERMINATION OF DENSITY. SPECIFIC GRAVITY WAS DETERMINED IN A 25-ML PRECISION-TYPE PYCNOMETER. DENSITY WAS OBTAINED BY MULTIPLYING THIS RESULT BY THE DENSITY OF WATER (0.99663 AT 80 F).

7. CALCULATION OF BULK MODULUS

$$BM = KD\ (V_O)^2$$

WHERE BM = BULK MODULUS, PSI.
D = DENSITY, G PER ML.
V_0 = SOUND VELOCITY, FPS.
K = PROPORTIONALITY CONSTANT FROM FPS TO CGS SYSTEMS; DENSITY: G PER ML x 62.43 = LB PER CU FT, LB PER SQ FT ÷ 144 = PSI, POUNDALS FORCE ÷ 32.174 = LB FORCE.

$$K = \frac{62.43}{(144)(32.174)} = 0.013475$$

8. <u>RESULTS</u> (TEMPERATURE 80±1 F)

FLUID CODE	SING-AROUND FREQUENCY CPS	µSEC PER CYCLE	VELOCITY OF SOUND FPS	DENSITY G PER ML	BULK MODULUS PSI	CALCULATED BULK MODULUS OF EMULSION (SEE METHOD BELOW)
WATER	22,396	44.651	4725.7 STANDARD	0.99663	300×10^3	-
EMULSION: 80% FLUID B 20% WATER	20,960(1)	47.710	4423	0.91055	240×10^3	246×10^3
EMULSION: 90% FLUID B 10% WATER	21,083	47.432	4449	0.89966	240×10^3	240×10^3
PURE FLUID B	21,010	47.596	4433	0.88853	235×10^3 (2)	-

(1) SINGLE READING OBTAINED BEFORE EQUIPMENT FAILURE.
(2) REFERENCE (3) LISTS A VALUE OF 215×10^3 FOR MIL-O-5606 AIRCRAFT PETROLEUM-BASE HYDRAULIC FLUID.

9. <u>CALCULATION OF BULK MODULUS OF EMULSIONS</u>. REFERENCE (4) ASSUMES THAT THE VELOCITY OF SOUND IN AN EMULSION IS A LINEAR FUNCTION OF THE BULK MODULI OF THE COMPONENTS AND THEIR RESPECTIVE VOLUME FRACTIONS IN THE EMULSION. THUS IS DERIVED THE EQUATION:

$$BM_E = \frac{(BM_O)(BM_W)}{(X)(BM_W) + (1 - X)(BM_O)}$$

WHERE BM_E = BULK MODULUS OF THE EMULSION.
BM_O = BULK MODULUS OF OIL.
BM_W = BULK MODULUS OF WATER.
X = VOLUME FRACTION OF OIL.

THIS EQUATION WAS USED TO CALCULATE DATA IN THE LAST COLUMN OF RESULTS.

REFERENCES

(1) GREENSPAN, M., AND TSCHIEGG, C. E., "SING AROUND ULTRASONIC VELOCIMETER FOR LIQUIDS," REV. SCI. INSTR., VOL. 28, P. 897, 1957

(2) GREENSPAN, M., AND TSCHIEGG, C. E., "SPEED OF SOUND IN WATER BY A DIRECT METHOD," J. RES. NATL. BU. STD., VOL. 59, P. 249, 1957

(3) PEELER, R. L., AND GREEN, J., "MEASUREMENT OF BULK MODULUS OF HYDRAULIC FLUIDS," ASTM BULL., P. 51, JAN 1959

(4) ALLINSON, P. A., "THE VELOCITY OF SOUND IN EMULSIONS," J. COLLOID SCI., VOL. 13, P. 513, 1958

VISCOSITY OF EMULSIONS[1] AT 130 F

OIL, %	CS (DETERMINED BY D455)	SSU (CONVERTED FROM CS BY D446)	SSU (DETERMINED BY D88)
100	21.3	104	106
90	25.3	121	125
80	38.6	180	175
70	53.6	249	238
60	61.8	287	337
50	140.3	651	509

[1] THESE DISTILLED WATER EMULSIONS WERE NON-NEWTONIAN LIQUIDS; THEREFORE, RESULTS ARE EFFECTED BY BORE OF KINEMATIC (D445) TUBE. ALL ABOVE CS DATA, TAKEN WITH 300 SERIES TUBE, ARE REPORTED FOR COMPARISON ONLY. ALL EMULSIONS WERE WATER-IN-OIL TYPE.

STABILITY OF EMULSIONS TO TEMPERATURE CYCLING

METHOD. EMULSIONS OF FLUID B, CONTAINING 10, 25, AND 50 VOL. PERCENT SEAWATER, WERE PREPARED AT 150 F BY 5-MIN STIRRING IN THE APPARATUS OF FTM 791 METHOD 3201.5 (SAME AS SPECIFIED IN MIL-L-15017A). THREE REPLICATES OF EACH EMULSION WERE PREPARED; ONE WAS STORED OVERNIGHT AT 0 F, ONE AT 50 F, AND ONE AT 150 F. EACH WAS ALLOWED TO RETURN TO AMBIENT TEMPERATURE (75 F) FOR 8 HR DAILY. READINGS OF VOLUME OF OIL, WATER, AND EMULSION WERE TAKEN AFTER EACH TEMPERATURE CHANGE EXCEPT FOR FOURTH AND FIFTH DAYS (WEEKEND). THE TEST WAS CONCLUDED AFTER 7 DAYS.

RESULTS. ALL EMULSIONS CYCLED AT EITHER 0 OR 50 F REMAINED COMPLETELY EMULSIFIED FOR 7 DAYS WITH NO EVIDENCE OF EITHER OIL OR WATER SEPARATION. EMULSIONS CYCLED AT 150 F SEPARATED INTO OIL- AND WATER-RICH EMULSIONS IN THE FIRST 2 DAYS, AFTER WHICH NO FURTHER CHANGES WERE NOTED. NO WATER APPEARED. VOLUME PERCENT OF OIL AND EMULSION ARE SHOWN BELOW.

DAYS STORED	VOL. % SEAWATER					
	10		25		50	
	VOL. %		VOL. %		VOL. %	
	OIL	EMULSION	OIL	EMULSION	OIL	EMULSION
1	80	20	0	100	0	100
2 TO 7, INCLUSIVE	85	15	55	45	25	75

Appendix C
IMO Pump Tests – Operational Data[1]

Run No.	Hours' Operation Start	Hours' Operation Stop	Hours' Operation Total	Fluid	Filter Pressure Drop psi	Pump Inlet Suction Pressure psi	Pump Inlet Temperature F	Pump Outlet Pressure psi	Pump Outlet Temperature F Average	Pump Outlet Flow Rate GPM Average	Observations of Sump for Foaming	Observations of Sump for Rusting	Other Observations
1A	0	50	50	Approved MS 2110-H	1-4	10	127	1000	135	23.6	No foaming	None	-
1B	50	100	100	Same as above + 1 vol. percent aqueous sodium chromate[2]	12-15	10	131	1000	139	23.3	No foaming	None	-
1C	100	150	150	Same as in 1B + 1 vol. percent sea-water	12-15	10	131	1000	139	23.5	No foaming	Rust on walls of vapor space from condensation.	Filter loaded with fine yellow scum. Pump disassembly showed outer periphery of bearing block rusted. No other parts appeared unusual.
2A	0	50	50	Approved MS 2110-H	2-4	10	133	1000	140	23.6	No foaming	None	-
2B	50	286	286	Same as above + 1 vol. percent each seawater and aqueous sodium chromate	10-12	10	132	1000	141	23.5	No foaming	Rust on walls of vapor space area from water condensation.	Disassembly showed bearing block rusted (see Figure 11) and filter clogged by yellow sludge (see Figure 9). All other parts appeared normal.
3A	0	100	100	Fluid Code B	4-6	10	133	1000	142	23.8	No foaming	None	-
3B	100	150	150	Fluid B + 2% sea-water	10-12	10	136	1000	142	24.5	No foaming	None	Filter clean. Bearing block clean.
3C	150	200	200	Same as above + total of 5% sea-water	10	10	136	1000	140	24.0	No foaming	None	-
3D	200	450	450	Same as above + total of 10% sea-water	10	10	134	1000	140	24.4	No foaming	Rust on walls of vapor space area.	Filter clean. Bearing block clean.

Run No.	Hours' Operation Start	Stop	Total	Fluid	Filter Pressure Drop psi	Pump Inlet Suction Pressure psi	Temperature F	Pump Outlet Pressure psi	Temperature F Average	Flow Rate gpm Average	Observations of Sump for Foaming	Rusting	Other Observations
4A	0	500	500[3]	Fluid B + 10% seawater	10-12	10[4]	135	1800	147	21.5[5]	No foaming	Rust on walls of vapor space.	Bearing block and filter were clean.
4B	500	1000	1000[3]	Same as above	10-12	10	135	1800	148	21.[illegible][5]	No foaming	Rust on walls of vapor space	Bearing block was clean (see photographs, Figures 12 and 13). Filter was clean (see photographs, Figure 10.)

1 - On runs containing seawater, water content was maintained by daily additions of fresh water as required. Water content by distillation determined daily.
2 - Solution contained 22 1/2 weight percent sodium chromate, Na_2CrO_4.
3 - In Run 4, pump was secured from 0000 to 0800 Monday through Friday. Fluid was drained at 500 hr and replaced after inspection of parts. Only other fluid drainage was at completion of run.
4 - Minimum suction pressure before cavivation was 14-in. mercury vacuum.
5 - Flow rate was essentially constant throughout the test. Maximum variation of individual readings from the average was ±0.2 gpm.

APPENDIX D
IMO PUMP TESTS - NOISE DATA

Run No.	Fluid	Structureborne[1] Broad-band	Structureborne[1] Rotor Pulse	Fluidborne[2] Broad-band	Fluidborne[2] Rotor Pulse	Airborne[3] Broad-band	Airborne[3] Rotor Pulse
1A	MS 2110-H	107	81	173	169	80	68
1B	Same as above + 1% sodium chromate	105	78	172	169	79	70
1C	Same as above + 1% seawater	108	71	170	167	79	69
3A	Fluid B	107	84	170	168	78	70
3B	Same as above + 2% seawater	107	85	170	168	78	69
3C	Same as above + total of 5% sea-water	104	70	167	165	77	61
3D	Same as above + total of 10% sea-water	104	71	168	166	78	65

[1] Broad-band = total energy from approximately 10 to 10^4 cps. Rotor pulse = energy of maximum frequency observed. Measured with Massa Model 198-A accelerometer mounted on suction end of IMO pump base. Units in acceleration decibels. Reference point 1×10^{-3} cm per sec^2.

[2] Measured with Atlantic Research Corporation BD-25 pressure transducer located approximately 6 in. downstream of pump outlet. Signal output analyzed with Western Electric Company Model 3A-4A analyzer and recorder. Units in pressure decibels. Reference point 2×10^{-4} dynes per cm^2.

[3] Measured with an Altec Lansing microphone suspended 3 ft above pump center. Signal analysis and reference point same as in Note 2.

APPENDIX E
IMO PUMP TESTS

WEAR DATA ON ROTORS AND BUSHINGS

Measurements Taken Before and After Run No.	Measurements of Pump Rotating Parts, Mils							Measurements of Bushings					
	Major Diameter Change			Bearing Surfaces				Diameter Change, Mils			Weight Change, MG[4]		
					Power Rotor								
	Left Idlers[1]	Power Rotor[2]	Right Idlers[1]	Left Idler[1][3]	Suction End[3]	Power End[3]	Right Idler[3]	Left Bushing	Center Bushing	Right Bushing	Left Bushing	Center Bushing	Right Bushing
1A + B + C	+0.2	+0.4	+0.2	±0.0	-0.6	-	±0.0	-0.3	-0.2	+0.4	-3.8	-0.5	-1.5
2A + B	±0.0	-0.1	-0.1	-0.1	+0.1	-	-0.1	-0.3	±0.0	+0.4	-	-	-
3A + B	-0.1	-0.2	-0.1	-0.1	+0.1	-0.1	-0.1	+0.4	+0.3	+0.1	-0.2	-1.1	-1.4
3C + D	±0.0	±0.0	-0.1	±0.0	-0.1	±0.0	±0.0	±0.0	-0.2	+0.2	-	-	-
4A	±0.0	-0.1	+0.1	±0.0	-0.2	-0.2	+0.1	-	-	-	-63.0	-155	-65.0
4A + B	-0.1	-0.4	-0.2	-0.2	-0.1	±0.0	-0.1	+0.3	+0.7	+0.1	-175	-317	-171

1 - Average of seven readings on each of four idlers. - = decrease in diameter; + = increase in diameter

2 - Average of 28 readings equidistant along rotor.

3 - Average of two readings equidistant along bearing surface.

4 - - = loss.

WEAR DATA ON PUMP BARREL - RUN 4[1]

MEASUREMENT STATION, IN. FROM SUCTION END	LEFT IDLER BARREL		CENTER BARREL			RIGHT IDLER BARREL	
	MEASUREMENT NO.						
	1	2	3	4	5	6	7
			SUCTION END SECTION				
1/2	0	0	+0.05	-0.05	+0.05	-0.05	-0.05
2	-0.05	-0.05	0	-0.10	0	-0.05	0
4	+0.25	+0.35	0	0	-0.05	-0.25	-0.10
6	-0.05	0	-0.05	0	0	-1.70	-1.30
			CENTER SECTION				
6 1/2	0	+0.05	0	0	-0.05	-0.80	-1.0
8 1/4	0	-0.05	0	0	-0.05	-1.30	-1.45
10 1/4	0	0	-0.05	0	-0.05	-0.05	+0.05
12 1/4	0	-0.05	-0.15	0	0	0	+0.05
			DISCHARGE END SECTION				
12 3/4	-0.05	0	0	0	0	0	0
14 1/2	-0.05	-0.10	0	-0.05	0	-0.5	0
16 3/8	-0.05	0	-0.05	+0.05	-0.05	-0.5	0
18 1/4	0	-0.05	0	0	0	-0.5	0
TOTAL: PLUS	+0.60		+0.15			+0.10	
MINUS	-0.55		-0.75			-8.25	
DIFFERENCE	+0.05		-0.60			-8.15	

[1] READINGS IN MILS. MINUS SIGNIFIES REMOVAL OF METAL OR INCREASE IN DIAMETER. DUPLICATE MEASUREMENTS AT EACH STATION WERE APPROXIMATELY 60° APART RADIALLY ON EACH OF THE THREE BARRELS. MEASUREMENTS WERE MADE WITH SHEFFIELD AIR GAGE SENSITIVE TO ±0.1 MIL.

APPENDIX F
IMO PUMP TEST OF FLUID B, RUN 4
WEIGHT CHANGES OF METAL SPECIMENS[1]

METAL OR ALLOY	SPECIMEN LOCATION		
	IN AIR SPACE ABOVE FLUID	HALF SUBMERGED	TOTALLY SUBMERGED
SAE 1010 STEEL	-0.01	-0.03	-0.01
CAST IRON	+0.01	+0.03	NONE
304 STAINLESS STEEL	-0.03	-0.03	-0.02
ALUMINUM	+0.02	NONE	+0.03
COPPER	-0.02	-0.69	-0.93
NAVAL BRASS	+0.06	-0.59	-0.62
ADMIRALTY BRASS	-0.09	-0.13	-0.32
ALUMINUM-BRONZE	+0.05	-0.17	-0.17
90:10 COPPER-NICKEL	-0.03	-0.03	-0.03
70:30 NICKEL-COPPER (MONEL)	-0.02	-0.04	+0.04

[1] WEIGHT CHANGES ARE GIVEN IN MG PER C㎡. METAL SPECIMENS WERE APPROXIMATELY 3/4 x 3 x 1/16 IN. THICK. - SIGNIFIES WEIGHT LOSS; + SIGNIFIES A WEIGHT GAIN.

APPENDIX G
SPECIFICATION FOR EMULSIFIABLE HYDRAULIC LUBRICATING OIL

1. ALL SECTIONS OF MILITARY SPECIFICATION MIL-L-15017A OF 11 APRIL 1962 APPLY EXCEPT AS NOTED BELOW.

2. <u>TABLE I. CHEMICAL AND PHYSICAL REQUIREMENTS</u>. DELETE COLUMNS HEADED 2075H AND 2135H. CHANGE 2110H TO 2110E-H. DELETE WORK-FACTOR TEST AND ADD OXIDATION AND PUMP TESTS, AND CHANGE LIMITS OF OTHER TESTS AS SHOWN BELOW.

REQUIREMENT	LIMIT
VISCOSITY(A), CS, 0 F (DETERMINED)	3600 MAXIMUM
210 F	5.3-6.7
NEUTRALITY, QUALITATIVE	NEUTRAL OR ALKALINE[1]
ACID AND BASE NUMBER, MAXIMUM	1.5
SAPONIFICATION NUMBER, MAXIMUM	3.0
EMULSION, SEAWATER AT 130 F	3
WATER, % MAXIMUM	0.5
SULFUR, % MAXIMUM	0.75
OXIDATION TEST, HR TO REACH NEUTRALIZATION NUMBER OF 2.0, MINIMUM	1000
PUMP TEST - AVERAGE WEIGHT LOSS OF STEEL GEARS, MG, MAXIMUM	30
PUMP TEST - AVERAGE WEIGHT LOSS OF BRONZE BUSHINGS, MG, MAXIMUM	15

(A)CHANGES PROMULGATED IN BUSHIPS LTR SER 634A-476 OF 12 OCT 1962.

3. NOTES TO TABLE I OF MIL-L-15017A TO BE CHANGED AS FOLLOWS:

<u>PRESENT NOTES</u>
1. CHANGE TO READ NOTE 2.
2. DELETE.
3. CHANGE TO READ NOTE 4.
4. DELETE.
5. NO CHANGE.

ADD THE FOLLOWING:

NOTE 1. pH OF AQUEOUS LAYER 12 MAXIMUM. FLUIDS WITH AN ALKALINE REACTION SHALL BE FURTHER EXAMINED WITH RESPECT TO ALUMINUM ACTIVITY BY IMMERSING A SPECIMEN OF ALUMINUM (SPECIFICATION QQ-A-355, CONDITION T) IN THE SUMP OF THE PUMP TEST. WEIGHT LOSS SHALL NOT EXCEED 0.2 MG PER CM^2.

NOTE 3. SHALL REMAIN EMULSIFIED AFTER STANDING 60 MIN.

4. PARAGRAPH 4.6.1 - DELETE REFERENCE TO WORK-FACTOR AND RUST PREVENTION.

5. ADD NEW PARAGRAPHS 4.6.2 TO 4.6.4, INCLUSIVE.

4.6.2 OXIDATION TEST. THE OXIDATION TEST SHALL BE PERFORMED AS OUTLINED IN ASTM METHOD D943, EXCEPT AT TEST TEMPERATURE OF 150 F.

4.6.3 RUST PREVENTION. METHOD 4011 OF FED-STD-791 SHALL BE USED BUT WITH THE FOLLOWING MODIFICATIONS:

(1) USE 150 ML OF OIL.
(2) USE 150 ML OF SEAWATER.
(3) OPERATE STIRRER 1/4 HR DAILY.

THE TEST SHALL EXTEND FOR 30 DAYS. A RATING OF "PASS" SHALL BE LIMITED TO LIGHT RUSTING AS DEFINED IN THE METHOD.

4.6.4 PUMP TEST. THE TEST SYSTEM SHALL CONSIST OF A PESCO IP 349 P4 HYDRAULIC PUMP OR EQUIVALENT, A THERMOSTATICALLY CONTROLLED OIL COOLER, PRESSURE CONTROL AND RELIEF VALVES, FLOWMETER, RESERVOIR PIPING, AND AN OIL INLET TEMPERATURE INDICATOR OR RECORDER. AT THE START OF THE TEST, ALL PUMP PARTS SHALL BE OF FIRST QUALITY AND MATED BY PREVIOUS OPERATION. THE TWO STEEL GEARS AND FOUR BRONZE BUSHINGS SHALL BE WASHED IN BENZENE, DRIED, AND WEIGHED BEFORE ASSEMBLY. ADD 1 GAL OF THE FLUID PLUS 375 ML OF SEAWATER TO THE SUMP. (SYNTHETIC SEAWATER PREPARED BY METHOD 4011 OF FED-STD-791 MAY BE USED.) OPERATE THE PUMP AT 1000±50 PSI, 3600±100 RPM, PUMP INLET TEMPERATURE 140±5 F, AND A FLOW RATE OF 3.3 ± .3 GPM FOR 50 HR. A LOG SHALL BE KEPT TO INSURE THAT OPERATING CONDITIONS ARE MET THROUGHOUT THE TEST. THE LOG SHOULD INCLUDE READINGS DURING THE FIRST AND LAST HOUR OF THE RUN AND AT LEAST THREE ADDITIONAL READINGS SEPARATED FROM INITIAL AND FINAL ENTRIES AND EACH OTHER BY AT LEAST 8 HR. AFTER 50 HR OF OPERATION, THE SYSTEM IS DISASSEMBLED AND THE GEARS AND BUSHINGS CAREFULLY REMOVED WITHOUT SCRAPING THEIR SURFACES, WASHED IN BENZENE, AND WEIGHED.

6. RENUMBER PRESENT PARAGRAPH 4.6.2 AS 4.6.5.

Navy Marine Engineering Laboratory. Report 95 680J.
FLUIDS FOR SUBMARINE EXTERNAL HYDRAULIC SYSTEMS, by A. P. Evans. 20 January 1964. 58 pp. figs.
UNCLASSIFIED

A successful search was made for petroleum-base hydraulic fluids with rust-inhibiting qualities adequate to prevent rusting in submarine hydraulic systems contaminated with seawater. Rusting of such systems has been a serious service problem. Fluids of two types were found with considerably greater rust-inhibiting ability than currently used Navy hydraulic fluids. The type of fluid giving the better rust inhibition deviated from present hydraulic fluid specification requirements in that it emulsified readily with contaminating seawater, whereas the second type did not. Other necessary properties of both fluid types were satisfactory. Feasibility of using the emulsifying-type fluid in submarine hydraulic systems was shown by 1000 hr of satisfactory operation using a hydraulic system mock-up with full scale submarine system components in the

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